Report

by the

NASA
Biological and Physical Research

Research Maximization
And Prioritization
(ReMAP) Task Force

to the

NASA Advisory Council
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PREFACE

The ReMAP committee deliberated for several months to establish, for the first time, priorities and goals for OBPR and ISS research across disciplines. ReMAP findings and recommendations rest on a large foundation of work of hundreds of scientists who worked for thousands of hours, over months and years, to prioritize research within each OBPR scientific discipline. It is noteworthy that the committee was successful, during meeting deliberations, in establishing a rationale and strategies for prioritization of the overall research program for OBPR and for ISS.

The findings and recommendations in this report provide a framework for prioritizing a productive research program for NASA's Office of Biological and Physical Research (OBPR) and for the International Space Station (ISS).

The report identifies two overarching programmatic goals.

- The first involves research enabling human exploration of space.
- The second involves basic research of intrinsic scientific interest.

The broad OBPR program encompasses research using the ISS, shuttle, free-flyers and ground-based capabilities.

- The ISS has unique features not available on any other vehicle, including human tended, long duration (>1mo) exposure to microgravity.
    - ReMAP prioritized work that can be done on ISS with the US Core Complete[1] configuration,
    - ReMAP identified enhancements to the US Core Complete configuration which will enable a science driven program of highest priority research.

The context for establishing the ReMAP Task Force is multifaceted:
The President's FY2003 budget states: "This year, NASA will be working with the White House Office of Science and Technology Policy (OSTP) to engage the scientific community and establish clear high-priority, affordable science objectives with near-term focus on improving scientific productivity. The results of this review will help set the science agenda for Biological and Physical Research that will in turn drive how the Space Station is used. It should increase the efficiency and output of research at the Station, and realign NASA's Research and Development portfolio to reflect current priorities."

The NASA Advisory Council (NAC) requested that NASA's Office of Biological and Physical Research (OBPR) act upon the International Space Station Management and Cost Evaluation Task Force (IMCE) conclusion: "Scientific research priorities must be established and an executable program, consistent with those priorities, must be developed and implemented."

In consultation with OSTP and the Office of Management and Budget (OMB), OBPR assembled an *ad-hoc* external advisory committee, the Biological and Physical Research Maximization and Prioritization (ReMAP) Task Force, to assist OBPR in establishing a prioritized program for its research portfolio.

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[1] See definition, Appendix O

Basis of ReMAP activities:
The ReMAP Task Force has used the Terms of Reference (Appendix A) jointly developed by NASA, the OMB, and the OSTP, along with the charge to the Task Force from the NASA Administrator (delivered at the first and third meetings), to form the basis of its activities.

Acknowledgements:
The ReMAP Task Force commends the many dedicated NASA teams and contractor personnel who facilitated the compilation of this report. While these individuals provided extensive background information and offered constructive comments and suggestions, responsibility for the content of the final report rests entirely with the ReMAP Task Force. Further, the findings and recommendations in this report are those of the ReMAP Task Force.

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* denotes dissent, see Appendix N

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1.0 Executive Summary

Perspective:
NASA has a stake in some of the biggest intellectual problems in science: the origin of life, the nature of the solar system, human exploration outside the planet, and the characterization of Earth from space. In several areas of biological and physical research, solutions of very large, important questions require microgravity. ISS provides a unique environment for attacking these problems "as only NASA can." The committee was unanimous in the view that the ISS is unprecedented as a laboratory and is the *only* available platform for human tended research on long-duration effects of microgravity.

The Task Force has made the following primary findings:

- OBPR research includes work that is best performed on ISS, as well as studies best done on the ground or on other platforms such as the Shuttle or free-flyers.
- The highest priority research for ISS falls into two broad categories: research emphasizing human exploration of space, and that emphasizing intrinsic scientific importance and impact, with some work meeting both goals. Prioritization between these categories is a NASA programmatic decision.
- The assignment of priorities was done at the level of OBPR research themes and not at the level of individual research projects. The ranking of priority 1 to a given theme area constitutes our statement that there are very important research questions within this research theme, and does not suggest a blanket endorsement of all the projects within an area.
- According to the preliminary OBPR Implementation Analysis for ISS presented to ReMAP, at "US Core Complete" and at "US+ IP Core Complete,"[2] the capability to do high priority research is limited due to constraints imposed by crew time and lack of upmass capacity.

The Task Force has made the following primary recommendations:

- **ISS Research Productivity:** NASA must resolve the upmass and crew research time issues.
- **Current ISS Productivity:** As ISS nears completion, NASA should increase science priority and productivity on ISS.
- **Basic Research:** OBPR should include in its high-priority research portfolio, outstanding basic scientific research programs that address important questions in the physical and biological sciences, and which require long-term experiments on the ISS, based on their intrinsic scientific value.
- **Implementation of ISS Research Facilities:** NASA should ensure the implementation of high priority facilities, such as the centrifuge and habitats.

[2] See definitions, Appendix O

- **Fully Utilize Available Options for Space Research:** NASA should consider additional Shuttle science/commercial flight opportunities.
- **Science on ISS:** If enhancements to ISS beyond US Core Complete are not anticipated, NASA should cease to characterize the ISS as a science driven program.
- **Coordination with International Partners:** NASA should continue coordination of facilities development and research solicitations with the International Partners (IP), and attempt to address the IP concerns.

2.0 Specific Findings on Research Priorities

2.1 Task Force Priorities within OBPR Divisions

The 4 Divisions of OBPR are organized into 8 Research Themes as follows:

A. Bioastronautics Research Division
- A.1 Biomedical Research and Countermeasures
- A.2 Advanced Human Support Technology

B. Fundamental Space Biology Division

C. Physical Sciences Division
- C.1 Fundamental Microgravity Research
- C.2 Biotechnology and Applications
- C.3 Engineering Research Enabling Exploration

D. Research Integration Division
- D.1 Commercial Applied Sciences
- D.2 Commercial Engineering Research and Technology Development

For each of the 8 OBPR Research Themes: The Task Force analysis is summarized in the pages below, using the following categories:

- **Description** of the Division and each research theme(s)
- "**Meta-analysis"** by the Task Force of previous studies and reviews;
- **Findings** by the Task Force

A. Bioastronautics Research Division

- A.1 Biomedical Research and Countermeasures
- A.2 Advanced Human Support Technology

Bioastronautics research is designed to increase knowledge and improve the health and safety of humans in space. Several physiological adaptations to microgravity that increase the risk to human health in space have been identified. None are understood completely.

Bioastronautics translates new insight from fundamental research of the genetic, molecular, cellular, and organ effects of microgravity into treatments that prevent or ameliorate the untoward or undesirable consequences of space travel to humans. This research integrates understanding of different mechanisms compromised in microgravity as a basis for risk assessment and clinical testing of therapeutic countermeasures. It drives the development of miniaturized, automated, and remote sensing medical equipment to reduce cost and time for diagnosis or treatment, enhancing health and safety of crews and improving terrestrial health care in remote areas. Bioastronautics research fosters development of new medical interventions by studying physiological changes in microgravity that mimic, or may be identical to, human aging and disease states. This space research platform offers a unique test bed to evaluate radiation and biological protection that may improve terrestrial mitigation of disasters or terrorism.

A.1 Biomedical Research & Countermeasures

Description

Research in this theme area is focused on understanding effects of the space environment that may impair human health and performance, and on developing countermeasures that mitigate such problems. The research includes both ground- and space-based studies, and model studies with animals as well as clinical research with humans. The research includes studies in radiation health, integrated and organ system physiology, clinical/operational medicine in space, behavior and performance in the space environment, and environmental health.

While ground based studies are essential in this theme area to develop hypotheses and countermeasure protocols that can then be tested in space, research on the ISS is essential for evaluation of the long-term effects of the space environment and for flight testing of countermeasures. Although most radiation health investigations will be conducted on the ground using radiation sources such as the NASA facility at Brookhaven, some aspects of the space radiation environment cannot be duplicated on Earth and the effects must be studied with long-duration investigations in space.

Meta-Analysis of Previous Reports and Recommendations

There were a number of comprehensive previous reports available that included clear recommendations, increasing the Task Force confidence that their findings would be grounded in a wealth of data from the scientific community. The major sources for recommendations, and the basis of the following summary, are:

- *A Strategy for Research in Space Biology and Medicine in the New Century*, NRC, 1998
- *Review of NASA's Biomedical Research Program*, NRC, 2000
- *Safe Passage,* IOM, 2000

In addition to numerous disciplinary recommendations, the 1998 strategy report included a specific list of recommendations for high priority research.

The criterion for highest priority was research aimed at understanding and ameliorating problems that may limit the astronauts' ability to survive and/or function during prolonged spaceflight. Such studies include basic as well as applied research and ground-based as well as flight experiments. Accordingly, NASA should focus on aspects of research in which NASA has unique capabilities or that are underemphasized by other agencies.

High priority opportunities were identified in integrative and organ system physiology, in psychological and social issues and in health care. Development of effective, mechanism-based countermeasures was considered a necessary outcome of the recommended research in all areas.

Problems considered to have potentially serious consequences for long-duration spaceflight and research to address the problems are:

- **Loss of weight-bearing bone and muscle:** Carry out mechanistic studies on ground and in flight, with animal models and humans, leading to development of effective countermeasures. Studies should provide databases on the course of microgravity-related bone loss, muscle mass and tone in humans and its reversibility, and on pre-, in-, and post flight hormone profiles on humans.

- **Vestibular function, vestibular-ocular reflex and sensorimotor integration:** Highest priority should be given to studies designed to determine how the vestibular system compensates for loss/perturbation of gravitational cues in space and on the ground. Inflight recordings of peripheral and central nervous system responses should be made following stimulation of the otolith (gravity sensing component of the vestibular system).
- **Cardiovascular alterations:** Current knowledge of the magnitude, time course and mechanisms of cardiovascular changes in long-duration spaceflight should be extended, and the specific mechanisms underlying orthostatic intolerance upon return to 1 g should be determined.
- **Radiation hazards:** Determine carcinogenic and central nervous system risks following irradiation by protons and high atomic number-high energy (HZE) particles; determine how crew selection and space vehicle design affect the radiation environment of the crew; and determine whether effects of radiation and stress on the function of organs and other systems, including the immune system could produce additive/synergistic effects on host defenses in flight.
- **Psychological and social issues:** Highest priority should be given to interdisciplinary research on the neurobiological and psychological mechanisms underlying the effects of physical and psychological environmental stressors on the crew; experiments should include ground-based analogue settings as well as spaceflight. High priority should be given to evaluation of existing countermeasures and development of effective new countermeasures.
- **Health care in long-duration flight:** NASA should develop a strategic health care research plan to predict, develop and validate preventative, diagnostic, therapeutic and rehabilitative measures for care of astronauts.

Findings of the Task Force

The Task Force agreed on the following priorities for the biomedical research areas:

- **Radiation Health:** Priority 1. Radiation health hazards both on the ISS and for exploration beyond LEO pose a significant crew health risk.
- **Behavior and performance:** Priority 1. Evidence from isolated communities and previous space missions indicate that psychological issues can become serious, and could potentially become mission destroying. This is even more critical because the ISS crews are, and future exploration crews are likely to be, multicultural.
- **Physiology** (Integrated and Organ System Physiology): Priority 1. A range of biomedical areas involve potentially serious challenges to crew health in long-duration space flight, specifically those systems sensitive to gravitational changes including bone, muscle, cardiovascular, neurovestibular and endocrine systems.
- **Clinical/Operational Medicine:** Priority 1. NASA management must decide the acceptable level of risk for dealing with crew illness and injury on various space platforms and to achieve the capability to provide this level of care. First priority is recommended only for the study of the clinical/operational medical problems that require research (not equipment development) to achieve this goal, and that address high likelihood, high consequence areas for crew health.

- **Environmental Health:** (Includes aspects of Gravitational Ecology) Priority 4. This research enables understanding of the environmental health risks that occur because of microgravity and the confined and isolated living quarters of space. Toxicology and microbiology measurements and standards development take place as part of routine operations on both Shuttle and Station, and there was little evidence in the long life of Mir that microbial contamination was a major issue. Additionally, no specifically testable hypotheses have been developed concerning potential environmental health risks directly related to the space environment.

The Task Force agreed that the highest priority research should be in those areas where problems could lead to significant limitation or even termination of ISS or exploratory space missions. Thus, the highest priorities should be based on research aimed at understanding and eliminating problems that may limit astronauts' health or function during prolonged space flight. With three astronauts on board ISS at US Core Complete and a total of 20 hours per week devoted to "research" (of that, only about 9 hours are available for OBPR research), it is clear that this will limit the amount of human tended research that can be completed in space. The science priorities for human health and safety research should be given a top priority in research-related activities of the crew.

Ground based research should be aimed at development of hypotheses that can then be tested in space. While the ISS is the only platform for long-term studies and research that requires only short exposure to microgravity could be accommodated on Shuttle, both currently require a long lead time for assignment to, and preparation for, actual space flight. This requires that much of the BRC research be focused on ground-based studies to provide the basis for experiments that will eventually be carried out in space, to ensure the continuity of a group of high quality investigators, and to foster the training of graduate and post-graduate students as the next generation of committed investigators. In other words, scarce resources should not be used for low priority experiments in space just because that is all that can be done at this time. It is better to do high quality research on the ground than low quality research in space.

The use of animal model systems (most commonly rats and mice) is essential for investigations of physiological mechanisms that cannot be carried out on human subjects and to obtain a sample size that will give statistically significant findings within a reasonable timeframe. Such studies must be carried out in space as well as in 1 g, and include long duration experiments that require the ISS and the availability of adequate rodent habitats and a microgravity centrifuge.

Attempts to develop new countermeasures should be mechanism based and hypothesis driven. An example was provided in the sleep field. If astronauts in space have trouble sleeping, the development of countermeasures could be based on testing various sleeping pills. Or it could be based on developing a better understanding of the sleep and circadian clock system with the development of treatment based on that understanding at the mechanistic levels. The latter is hypothesis driven and should be the approach taken by NASA.

Studies on astronauts on ISS should have the same rigor as clinical research in humans on Earth, including a complete understanding of the medical and pharmacological history of the subjects. It is important that Biomedical Research and Countermeasures attract the very top scientists working in biological and biomedical research in the same way that some of the other science themes attract the very best in their respective fields. Thus, more consideration needs to be given to involving scientists that are engaged in high-quality research such as that funded by the NIH and NSF.

A.2 Advanced Human Support Technology

Description

The central and paramount challenge for human exploration of space is to provide an environment consistent with the sustained existence of personnel outside of Earth's atmosphere. This includes protection against ionizing radiation; control of temperature, pressure, humidity, and waste products within prescribed limits; provisions for adequately balanced food supply, potable water and hygienic water; and adequate physical activity. The research includes technologies enabling environmental monitoring and control, space human factors engineering, advanced life support, and advanced extravehicular activity (EVA).

For all research in this theme area, preliminary concepts and techniques can be developed through ground-based research. However, research on the ISS is essential to test promising technologies in the human-enabled space research environment, to confirm that they work properly or to perform rapid iterations on design parameters until they do work properly.

Meta-Analysis of Previous Reports and Recommendations

There were a number of well-researched previous reports available with clear recommendations, thereby increasing the Task Force confidence that their findings would be grounded in a wealth of data from the scientific community. The major reports consulted include:

- *Advanced Technology for Human Support in Space*, NRC, 1997
- *A Strategy for Research in Space Biology and Medicine in the New Century*, NRC, 1998
- *Safe Passage: Astronaut Care for Exploration Missions*, Institute of Medicine, 2001
- *Microgravity Research in Support of Technology for Human Exploration and Development of Space and Planetary Bodies*, NRC, 2000

From an analysis of these reports, it is evident that the key to understanding life support systems and their subsystems is the concept of homeostasis, or maintaining constant, optimal levels of various physical, chemical and biological systems necessary for life support. An important goal is to achieve, as close as practical, a closed ecological life support system requiring the input of a minimum of mass and energy and in which as many subsystems as possible utilize recycling, accommodated by the development of effective interfaces between bioregenerative and physio-chemical processes. To improve safety, efficiency, and reliability, and reduce crew maintenance and monitoring demands, risk-based prioritization of monitoring and control systems related to environmental chemical and microbial contaminants and life support processes are required for both steady state and off-nominal conditions. And, as NASA looks to longer duration space missions and possible planetary surface missions – lunar or Martian – advanced EVA technologies and understanding of human perception, cognition, performance, behavior and habitability issues become increasingly important.

High priority activities identified in the reports for each of the main research thrusts include:

- **Advanced Life Support**
  - Treatment and recovery of resources from air, water and solid waste, including technologies for system loop closure to minimize resupply
  - Optimization of plant growth facilities
  - Systems analysis and validation in integrated testing
- **Advanced Environmental Monitoring and Control**
  - Autonomous, miniaturized, low-mass, low-power, multi-use technologies to monitor the crew environment
  - Control strategies to integrate sensor platforms based on feedback
  - Systems validation during both nominal and off-nominal or transitory conditions
- **Advanced Extravehicular Activity**
  - CO_2, humidity and trace contaminant removal for life support
  - Regenerable closed-loop thermal control
  - Passive and active radiation shielding
- **Space Human Factors Engineering**
  - Optimization and modeling of crew interactions and human performance
  - Systems automation and improved human-machine interaction, including interaction with intelligent systems

Advanced Human Support Technology has great importance because many of the challenges in this area are potentially limiting for the next generation of human exploration missions. Additionally, this research addresses the efficiency of research and development funding; a concern discussed in the President's Management Agenda. Results of this research have the potential to significantly reduce upmass requirements and reduce crew time required for maintenance and monitoring (see Appendix G). This provides significant opportunities for lowering costs and expanding crew time available for research.

The Task Force Analysis

The Task Force rated the four AHST thrust areas as follows:

- **Advanced Environmental Monitoring and Control:** Priority 1. This research is a very high priority because of the potential for significant return on investment. Automated systems will free crewmembers from frequent system checks and managing environmental control settings. Performing maintenance as indicated by out-of-limits conditions rather than on a set schedule would save significant crew time and reduce replacement hardware needs. Smaller, lower mass, more reliable monitors would save both upmass and time. A stable and optimal environment will better support all in-flight studies in physiology. All future spacecraft would benefit from this technology and there might be important Earth-based applications as well.

- **Advanced Life Support:** Priority 1. (Includes aspects of Gravitational Ecology) This area is a major challenge for future exploration. It would be impossible to conduct exploratory class human exploration missions taking along all supplies and storing all wastes. A more closed loop system of recycling waste products (CO_2, dirty water, solid waste, etc.) into usable supplies will be of utmost importance. Additionally, current spacecraft such as the ISS and the Space Shuttle may use these technologies to improve operational efficiency. This research could also have important Earth-based applications.
- **Space Human Factors Engineering:** Priority 2. Improvements in this area might have payback in increasing work productivity and decreasing the incidence of errors on the ISS and in future missions. As flights lengthen, innovations in training will be needed for maintaining currency in standard and emergency procedures. There is, however, a strong background of human factors research and a great amount of experience already available to assess needs and make improvements as problems are identified and new systems are designed. Because the science is already fairly mature, advances in this area would not have as high an impact as in the top priority areas.
- **Advanced Extravehicular Activity:** Priority 4. While research projects in this area will allow incremental improvements in the current spacesuit, issues of maintainability, refurbishment, etc. may dictate an entirely new system for exploratory missions. However, definitive criteria for future missions that would guide the research await the selection of specific mission destinations and objectives. [It should be noted that EVA systems engineering, a separate activity from this research on fundamental advances, is performed in another organizational unit of NASA.]

B. Fundamental Space Biology Division

Description
In 1999-2000 several research programs in the former Life Sciences Division (notably gravitational biology and gravitational ecology) were combined to form the Fundamental Space Biology Division of OBPR. Fundamental Space Biology examines how plants and animals, including humans, react and adjust to the effects of different gravity levels, as well as the role of gravity in the evolution and development of terrestrial organisms and ecological systems. This allows rigorous and systematic determinations of physiological regulatory mechanisms compromised in microgravity as a basis for: more complete understanding of basic biology, risk assessment for future space travelers, and new approaches that enhance development of prophylactic and therapeutic countermeasures. Fundamental space biology research enables evaluation of microgravity effects on lower plant and animal cells where rapid reproduction cycles yield perturbations that extrapolate to human experience. It also provides unique opportunities using non-human models to reduce the complexity of variables related to transient and long-term microgravity effects on humans affected.

The Fundamental Space Biology theme is organized into six research thrust areas: molecular structures and interactions, cell and molecular biology, organismal biology, developmental biology, gravitational ecology, and evolutionary biology. The program relies heavily on ground-based supporting research, though the ultimate target of most of the research is space flight. The research in this area uses molecular, cellular, systems, and whole-body levels of inquiry to study the long-term effects of the microgravity environment on both simple (single-celled) and complex (plants and animals) organisms. The extent to which research has been integrated across levels of inquiry is not fully clear but is strongly encouraged when appropriate. Because the research examines biological systems for the long-term (including multiple life cycles) it requires the use of the ISS. Moreover, the research depends critically on superb habitats to house model organisms that vary in biological complexity; this "molecule to human" approach is severely constrained by the potential cancellation of the plant and rodent habitats. Without the ability to house and study complex systems like plants and mammals, the utility of information obtained from isolated cell culture becomes less sure.

Meta-Analysis of Previous Reports and Recommendations
Parts of this research theme have been analyzed extensively. Most external recommendations for NASA's research in space biology are provided in the following reports:

- *A Strategy for Research in Space Biology and Medicine in the New Century*, NRC, 1998
- *Review of NASA's Biomedical Research Program,* NRC, 2000

These reports conclude that the highest priorities for research should be given to studies of fundamental biological processes in which gravity is known to play a direct role, and to studies concentrating on mechanisms in combination with functional changes that are biologically and/or medically significant. Germane tests of biomedical significance include alterations in survival, mutation, integrity, or infection.

Three constituents of Fundamental Space Biology were given high priority, and two areas (Gravitational Ecology and Evolutionary Biology) were not evaluated in the NRC reports. It should be noted that this discipline-based prioritization was generated prior to the reorganization of the Fundamental Space Biology Division.

- **Cell Biology**:
  - Cellular systems that are known to be affected by gravitational force or by other aspects of the space environment should be emphasized.
  - Studies of cellular mechanoreception should include identification of the cellular receptor, investigation of possible changes in membrane and cytoskeletal architecture, and analysis of pathways of response, including signal transduction and resolution in time and space of possible ion transients.
  - Studies of cellular responses to environmental stresses encountered in spaceflight should include investigation of the nature of cellular receptors, signal transduction pathways, changes in gene expression, and identification and structure and function analysis of stress proteins that mediate the response.
- **Developmental Biology**:
  - Key model organisms should be grown through two complete life cycles in space to determine whether there are any critical events during development that are affected by space conditions
  - Studies should be performed to define the critical periods for development of the vestibular system. Critical periods for cellular proliferation, migration and differentiation, and apoptosis should be identified and the effects of microgravity on these processes assessed.
  - Investigations should be conducted on the influence of microgravity on the development and maintenance of the different neural space maps (vertebrate brains form and maintain multiple neural maps of the spatial environment, which provide distinctive, topographical representations of different sensory and motor systems), including those within the brain stem, hippocampus, sensory and motor cortices, and corpus striatum.
- **Plants, Gravity, and Space**:
  - Studies should concentrate on a few systems that would produce synergistic efforts between investigative groups. Use of a large number of models has created confusion and diluted effort. NASA is urged to select systems for future applications that are relevant to crop plants needed in long-duration travel.
  - Seed-to-seed experiments should be given top priority. This requires a superior plant growth unit.
  - Studies of mechanisms of graviperception and gravitropism in plants, using transgenic plants wherever possible, should receive a high priority. Studies should include other topics in studies of mammalian systems.
  - Lower priority consideration should be given to mechanisms of gravity detection in single cells.

A recurrent theme in the NRC reports was the necessity of adequate facility development. Experiments depend on superior apparatus to avoid confounding true gravity-related biological change with habitat effects, and providing high quality research facilities and equipment should be a high priority.

The Task Force Analysis

In ranking the research in this Division, the Task Force recognized that the reorganization of the FSB division emphasized a shift toward more interdisciplinary investigations, whereas the NRC reports evaluated a discipline-based organizational strategy whose areas do not have exact homology with the current FSB research areas. Thus, elements of a discipline are found in several of the current FSB research areas. For example, "Plants, gravity and space" is a major, but not exclusive, component of both "organismal and comparative biology" and "cell and molecular biology."

The Evolutionary Biology and Gravitational Ecology areas are newer components of the Fundamental Space Biology Division developed over the last two years; hence, they were not included in the NRC reports. These areas were evaluated from more recent NASA-sponsored workshop reports; as the Astrobiology Program sponsored by NASA's Office of Space Science has become more defined, the scope of these areas has narrowed further. Thus, the Task Force analysis in these nascent areas is based on less information than the wealth of data available in other areas, and the Task Force recommends that an external review group revisit the prioritization of these two areas in the future.

The Task Force rated the current research areas as follows:

- **Cell and Molecular Biology** (combine with elements of **Molecular Structures & Interactions and Cell Science and Tissue Engineering**): Priority 1. Studies should be truly focused on the response of biological systems to gravity, and not on general cell biology or molecular biology questions. Logically this should include the physical effects of space flight on organisms, such as static boundary layer effects on gas exchange, heat transfer, and diffusion-limited metabolic processes. Discoveries in this area have a high impact potential, and represent opportunities for synergy between the physical and biological sciences.
- **Organismal and Comparative Biology**: Priority 1. The investigation of the effects of microgravity on normal physiology, metabolism, and performance of mature animals and plants, with comparison and contrast among different organisms. Discoveries in this area are directly relevant to, and are necessary for, human biomedical research and development of countermeasures, and have a high impact potential.
- **Developmental Biology**: Priority 2. How space flight affects the development of multicellular organisms. Growth of plants and small mammals through two full generations in space will be necessary to detect and understand critical and/or reversible stages in development where altered gravity has effects that change, limit, or block normal development. Effects of microgravity on development of the gravity-sensing systems, such as the vestibular system, should be emphasized. A somewhat lower priority was assigned primarily because this research has application for human exploration of space only in the very distant future.
- **Evolutionary Biology**: Priority 4. The ISS offers the first opportunity to systematically investigate evolutionary pathways in space. The question of whether gravity drives evolution is interesting. Only simple, rapid cycling biological systems could be utilized on ISS, and the specific hypotheses that would be tested experimentally are not well formulated.

The area of **Gravitational Ecology** did not earn a ranking because the Task Force found that the research questions in this area were well represented in the Environmental Health and Advanced Life Support research areas. The Task Force therefore recommends that Gravitational Ecology research of importance be integrated with those programs.

The FSB research program requires habitats for rodents and higher plants and the centrifuge for large organisms, originally planned for incorporation on ISS in 2006 and 2008, respectively. With such a long-lead time, fundamental biology studies in the near term must focus on ground-based studies, which can provide the experimental basis for eventual space-based investigations. Ground based investigations also ensure the continuity of the population of high quality investigators, and foster the training of graduate and post-graduate students as the next generation of committed investigators.

Finally, the Task Force concluded that OBPR should broaden the participation of high caliber researchers in the biological and biomedical sciences into this research theme (e.g., those traditionally funded by NIH and NSF). More effort should be made to coordinate activities, minimizing duplication of research activity across agencies and reserving the use of scarce resources for studies where the gravitational field is the key independent variable.

C. Physical Sciences Division

C.1 Fundamental Microgravity Research
C.2 Biotechnology and Applications
C.3 Engineering Research Enabling Exploration

There are a number of reasons for conducting microgravity research in the physical sciences. ISS research will form the basis of navigation and measurement technologies (clocks and GPS) vital for life and travel in space, and improved life on Earth. The ISS laboratory allows the removal of buoyancy effects from complex reactive-flow systems (combustion, multiphase flow, granular flow, self-assembly, …), allows extended spatial gradients and time scales, and allows better flow control. A microgravity environment provides a broader, wider, and longer window to observe and measure slow and very slow flow, combustion, kinetics, phase transitions, and interfacial phenomena – that is, processes affected by convection, sedimentation, and hydrostatic pressure. Some examples of important physical sciences research in space are:

- Examination of the formation of soot precursors (newly discovered nanoparticles) and other pollutants that are biologically harmful when left unreacted.
- Understanding the kinetics and transport processes of cool flames that undergo auto-ignition, and cellular structure of flames and how this is related to composition, background, turbulence and chaos.
- Developing a way to create novel materials, such as clean, high-quality synthesis for ceramics
- Investigation of the organizing principles of colloids, which self-assemble and are used to study phase transitions and fluid behavior, and are a model for atomic systems.

There are also biological consequences to these investigations. To be able to leave low Earth orbit (LEO), life support technologies must be efficient, self-generating and self-sustaining. Microgravity fluid mechanics plays an essential role in most of these enabling technologies. Many of the observed physiological changes in living organisms under LEO are affected by fluid mechanics that, in turn, affects biological responses. Therefore, fundamental microgravity research in the physical sciences, which is closely coupled to analytical and numerical modeling, enhances the potential for understanding the results from experiments on biological systems.

This OBPR division is organized into 3 themes: fundamental microgravity research, biotechnology and applications, and engineering research-enabling exploration.

C.1 Fundamental Microgravity Research

Description

The Fundamental Microgravity Research theme includes basic research targeting the understanding of natural processes and taking advantage of the great reduction in gravity-driven convection and sedimentation, in gravity-limited interaction time, and in the virtual elimination of hydrostatic pressure on the macroscopic scale. Possible research subject areas are phase transformations; condensed matter physics; quantum degenerate gases, atomic clocks, kinetics, structure and transport; fluid stability and dynamics; thermophysical and physico-chemical properties in microgravity; and fundamental physical laws.

Few, if any, of the experiments in this theme area require the long-duration exposure to the space environment enabled by the ISS. Many could be flown on the Shuttle if access to the Shuttle for science experiments was provided. However, some fraction of the investigations does require extensive human intervention for experiment adjustment and iteration, or will require the superior facilities and greater power available on the ISS. Those experiments should be conducted on the ISS.

Meta-Analysis of Previous Reports and Recommendations

There were a number of well-researched previous reports available with clear recommendations, increasing the Task Force confidence that their findings would be grounded in a wealth of data from the scientific community. Reports found to be particularly useful were:

- *Setting Priorities for Space Research – Opportunities and Imperatives*, NRC, 1992
- *Setting Priorities for Space Research – An Experiment in Methodology*, NRC, 1995
- *ISS/IMCE Task Force Report* 2001
- *Microgravity Research Opportunities in the 1990's,* NRC, 1995
- *Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies,* NRC, 2000

Additionally, the NRC Committee for Microgravity Research is in the process of conducting a review of research programs in the Physical Sciences Division, of which this area of research is a major component. The results of this review are expected to be available by September 2002. While unable to share preliminary findings with the Task Force, Dr. Peter Voorhees, Chair of the NRC Committee, outlined the objectives of the on-going review and highlighted some of the best research results to have come out of this program to date. An exciting example is the first-ever stabilization of flame balls. These are spherical nonpropagating flames, predicted by Zeldovich[3] in 1944, but not observed until produced in the Microgravity Science Laboratory-1 flights (STS-83 and STS-94) aboard the Space Shuttle in 1997.

These reports are unanimous in the assertion that NASA should support long-term, fundamental research of the highest quality. Reports 4 and 5 specifically call out the following areas of high priority:

- **Fluid Mechanics and Transport Phenomena:** Research in surface tension-driven flows, capillary effects, multiphase flows, diffusive transport, and colloidal phenomena.
- **Combustion:** Highest priority is spacecraft fire safety. Other important areas are turbulent combustion, laminar premixed and diffusion flames, and sprays, because of technological significance on Earth.
- **Materials Science and Processing:** Nucleation kinetics and achievement of metastable phase states, Ostwald ripening and phase coarsening, solidification and microstructure development, thermophysical property determination.
- **Microgravity Physics:** Fundamental physics measurements, such as the test of the equivalence of inertial and gravitational mass; critical phenomena, including reduced-dimensional and dynamic studies, and atomic clocks.

[3] Zeldovich, Ya. B., Theory of Combustion and Detonation of Gases, Academy of Sciences (USSR), 1944.

The ISS/IMCE Task Force report "is unanimous that the highest research priority should be solving problems with long-duration human space flight, including the engineering required for human support." Some of the research in this program may apply, particularly combustion research applied to spacecraft fire safety, and surface tension-driven flows, capillary effects as well as multiphase flow research can be directly applied to propulsion and power systems, but the bulk of Fundamental Microgravity Research is not on the critical path for supporting human spaceflight.

The Task Force Analysis

- **Microgravity Physics.** Priority 1* (see below for definition). This theme area (including the OBPR identified thrust areas of condensed matter; fundamental laws; phase transformation[4]; fluid stability and dynamics; kinetics, structure and transport; and energy conversion) includes a number of excellent projects in small, single investigator physics: flame balls, fluidics, phase transitions[5], and granular flows are examples. Other current areas of interest are cold atoms, Bose-Einstein condensation and degenerate Fermi gases; and atomic clocks. These studies should be considered as part of a single program in microgravity physics encompassing research of the most fundamentally important scientific problems.
- It would be inappropriate for the Task Force to prioritize among the projects which lie within this thrust area. Furthermore, on the basis of scientific quality alone, the work in fundamental microgravity cannot be differentiated from work in other areas such as biology.
- The biomedical theme areas given a priority 1 ranking address major issues for the human exploration of space while most of the physical sciences theme areas do not. As a consequence, the physical sciences working group discussed the priority assignment for the physical sciences theme areas at length considering a ranking of priority 1 or priority 2. The priority 1* ranking conveys the conclusion that these areas contain projects that deserve a priority 1 ranking based on scientific merit alone, but that many of them lack a direct connection with human space exploration. Of course, those physical science projects that impact human space exploration directly should receive a priority 1 ranking.
- **Thermo-physical, physical-chemical properties:** Priority 3. Much previous work has already been performed in this area. Specific expectations for major advances using the microgravity environment are not well documented.

Some of this work is purely knowledge driven, with no apparent connection to the more applied NASA missions. Some, for example flame balls and fluid mechanics, connect directly to a legitimate concern for astronaut safety (flammability) or spacecraft operation (pumping liquid fuels). Both types of research are appropriate. However, for the purely knowledge driven it is even more essential for NASA to ensure that only excellent research is chosen, and that the highest quality researchers are recruited. The best/most successful work in this area has been and will be hypothesis driven; that is, research on long duration exposure to microgravity used to test specific, very well defined hypotheses based on extensive ground-based research.

[4] See Appendix J note #10
[5] See Appendix J note #9

C.2 Biotechnology & Applications

Description

The Biotechnology and Applications theme is composed of the more applied research sponsored within the Physical Sciences Division. The research is focused on hardware and systems development for biological research in microgravity, including tissue engineering capability, as well as focused research for Earth-based and space-based applications The theme encompasses five distinct areas of research: physical effects in cell science and tissue engineering; structural biology; energy conversion and chemical processing; material synthesis and processing; and bioinspired and microfluidics technologies.

Both the Cell Science and Tissue Engineering and Structural Biology research thrusts contain research elements that require the ISS environment. Energy Conversion may not require the long-duration exposure to space, but some experiments may require the multiple iterations and adjustments made possible in a human tended environment. For materials synthesis and processing, gravitational processes play a major role in controlling the reactions, porosities and morphologies of products, but again, the long-duration requirement is not clear. There is no clear role for the microgravity environment in bioinspired and microfluidics technologies.

Meta-Analysis of Previous Reports and Recommendations

The primary report referred to for this analysis was:

- *Future Biotechnology Research on the International Space Station*, NRC, 2000

The cell science and tissue engineering and structural biology components of this research theme area have been reviewed thoroughly, with primary recommendations in the above document. The other areas covered in this OBPR theme have been less extensively reviewed. Task Force conclusions in these areas are not made with the same level of confidence as those based on a wealth of data from the scientific community.

Cell Science

The cell science and tissue engineering program focuses on perturbations encountered by cells as a consequence of the transition to microgravity environments. The principal goal of the ground based and microgravity research is to gain necessary understanding for the cellular basis of human adaptation to space. In addition to expanding the knowledge base of microgravity influences on cell structure and function, the program has the potential, in a broad biological context, to have significant impact on cell science and tissue engineering.

The NRC Task Group recommend that narrowing the broad sweep of the current cell science program may focus instrument development efforts and accelerate progress. Limitations that were identified in NASA-funded ground based studies and experiments carried out on Shuttle missions were to a large extent attributed to duration of flights and availability of space and equipment. These limitations will be, to a significant extent, alleviated by the ISS. The NRC also concluded that appropriate experimental controls for space-based cell science experiments have not yet been determined, and research should be more closely coordinated with the life sciences areas of OBPR's research portfolio. Finally, the NRC concluded that NASA should broaden outreach to increase the participation of the science community and the number of excellent outstanding research investigations proposed.

NASA and NIH collaborations, through joint development of a Center for Three-Dimensional Tissue Culture, have yielded new options for cell and tissue propagation in areas that have been refractory to traditional approaches. A recent program review at that center found that it has been highly successful at attracting a number of excellent researchers to use the NASA Rotating Wall Vessel Bioreactor (NASA tissue culture technology). Involvement of NIH scientists in NASA-oriented research has enhanced the research by NASA scientists. Continuation of such research should involve joint experiments on the Space Station that could be performed and monitored using devices operated at the NIH facilities

Structural Biology

The NRC review of NASA's structural biology research was initiated in part because of past criticisms of the program (NASA Position [Spring 1998], *The American Society for Cell Biology*, http://www.ascb.org/publicpolicy/nasareport.html). The NRC Task Group solicited opinions, both in person and in writing, from a wide cross-section of scientists who use crystallographic techniques for macromolecular structure studies, heard reports from NASA scientists and engineers concerned with the program and made two site visits to laboratories involved in instrumentation development.

The NRC Task Group concluded that the program has had very limited impact on structural biology to date. The NRC Task Group found "The results from the collection of experiments performed on microgravity's effect on protein crystal growth are inconclusive. The improvements in crystal quality that have been observed are often only incremental, and the difficulty of producing the appropriate controls limit investigators' ability to definitively assess if improvements can be reliably credited to the microgravity environment. To date, the impact of microgravity crystallization on structural biology as a whole has been extremely limited." The members of the NRC Task Group were very impressed by the prototype of the automated hardware developed under NASA grants for growing, selecting and cryo-preserving crystals. Recognizing that the Space Shuttle is not the optimum environment for these studies, it was the consensus of the NRC Task Group that the program be allowed to continue on the ISS until such time as its usefulness can be further assessed. Specifically, the NRC Task Group recommended:

> "At present, the primary goal of NASA's protein crystal growth program should be to demonstrate microgravity's effect on protein crystal growth and to determine whether studies of macromolecular assemblies with important biological implications will be advanced by use of the microgravity environment. To this end, the task group proposes that NASA instigate a high-profile, nation-wide series of grants to support researchers engaging in simultaneous efforts to get both the best possible crystal on the ground and the best possible crystal in space of biologically important macromolecules. The projects funded by these grants should address the uncertainties that have plagued the NASA protein crystal growth program, by using the ISS for a reliable, long-term microgravity environment, by comparing space-grown crystals to the best ground crystals, and by focusing on challenging systems and hot scientific problems. Their results should definitively show whether the use of microgravity can produce crystals of a higher quality than those grown using the best technologies available on Earth. If none of the projects produces a space-grown crystal that enables a breakthrough for the structure

determination of a biologically important macromolecular assembly, then NASA should be prepared to terminate its protein crystal growth program. However, if the projects supported by this high-profile, nationwide series of grants succeed in validating the use of crystallization in microgravity to tackle important and challenging problems in biology, demand for the facilities on the ISS can be expected to increase." – f*rom Executive Summary* (page 8).

The Task Force Analysis
The Task Force gave the following priority rankings for elements of this theme:

- **Structural Biology** - Priority 3. The program to date has had a very limited impact on structural biology. The prototype-automated hardware developed is impressive. It is important that this program attempt to resolve the issue of whether the microgravity environment can be a valuable tool; therefore the Task Force strongly endorses the NRC recommendation quoted above in the meta-analysis.
- **Materials Synthesis & Processing** - Priority 4. Primarily ground-based research with some relevance, particularly in the area of nanomaterials. However, the Task Force felt this area has lower potential for NASA's space-research portfolio than many other areas reviewed.
- **Bioinspired and Microfluidics Technologies** - Recommend NASA consider termination. The cross-disciplinary program was designed to integrate physical and biological sciences and strengthen NASA-wide technology development to enable new capabilities for the full and effective utilization of ISS research facilities. However, there is no clear role for the microgravity environment in this research or clear priority for NASA/OBPR funding.

Additionally, the Task Force recommends that the Cell Science and Tissue Engineering research be programmatically integrated with Cell and Molecular Biology research in the Fundamental Space Biology Division. The capabilities developed in the cell science and tissue-engineering area are essential for much of the fundamental biology research. A cogent case can be made that organismal studies are necessary to obtain understanding of a microgravity impact on physiological function. Yet, to mechanistically address microgravity-linked perturbations requires pursuit of problems at the cellular level. Exploring influences of microgravity on organisms and cells need not be mutually exclusive. Rather, these approaches are compatible, synergistic and a viable basis for research integration.

The Task Force also recommends that the Energy Conversion research be integrated with the other basic microgravity research in the Division. The program addresses important scientific questions that include the importance of low temperature chemistry on autoignition, the interplay between flame structure and convection on the soot growth process, the interaction between turbulent flamelets and the environment, and the effects of solutal capillary effects on the burning rate of fuel droplets. The program has a successful track record that it reflected by major contributions in combustion research, but is fundamentally similar in approach to the other small physics investigations supported by the Division.

C.3 Engineering Research Enabling Exploration

Description

Engineering Research Enabling Exploration emphasizes fundamental and applied engineering research specific to the design and engineering of space-based systems enabling human exploration of space. Specific subjects of interest include fire safety and fluid system engineering, technologies for propulsion and power, radiation protection, mission resource production, and biomolecular systems technology and sensors.

Very little of this research specifically requires long-duration access to the space environment. Much of the research can be performed in ground-based facilities and some research requiring access to space could be performed on the Shuttle. However, some investigations (for example, the testing of fire safety or propulsion and power systems) will require the superior facilities and greater power available on the ISS, or will require human intervention for experiment adjustment and iteration. These experiments should be flown on the ISS.

Meta-Analysis of Previous Reports and Recommendations

There were a number of well-researched previous reports available with clear recommendations, increasing the Task Force confidence that their findings would be grounded in a wealth of data from the scientific community. The primary reports used in this analysis were:

- *Microgravity Research Opportunities for the 1990*, NRC, 1995
- *Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies,* NRC, 2000

The fundamental phenomena affected or dominant in reduced gravity have been identified and high-priority research areas have been recommended. The specific areas identified for high priority research are:

- **Surface or interfacial phenomena** (effects stemming from surface wetting and interfacial tension)
- **Multiphase flow and heat transfer** (referring to the flow of more than one fluid phase in pipes, pumps, and phase change components, and the flow in porous media, exemplified by the flow of fluids in the packed and fluidized particulate beds used in chemical reactors)
- **Multiphase system dynamics** (deals with the global instabilities that may occur in multiphase systems)
- **Fire phenomena** (fire detection and suppression on board, also relating to some power generation and propulsion systems)
- **Granular materials** (referring to such topics as the response of granular media and soils to geotechnical loads and the flow of granular materials in chutes and hoppers)
- **Solidification and melting** (referring to the phase change of a liquid to a solid, as occurs in casting or welding)

In addition, the report lists recommendations for using ISS to conduct long-duration microgravity scientific research and assessing the efficiency and suitability of many of the systems and subsystems important to human and robotic exploration in space.

The research directly addresses challenges at the interface between the physical sciences, engineering, and integrated systems for human exploration in space. This research supports the long-duration (~ 20 years into the future) vision of NASA for space exploration. The fundamental research in multiphase flow and heat transfer that has been recommended in the second report is directly relevant to engineering research enabling exploration in systems for propulsion and power, for thermal management of fluid systems, in spacecraft environment as well as for crew comfort, and for mission resource production. As a concrete example of the intersection between interfacial phenomena and multiphase flow boiling heat transfer can be identified. Flow boiling is the simplest reliable means for circumventing the enormous bubble growth problems in microgravity, for greatly reducing system size and weight, for achieving order-of-magnitude increase in heat transfer corresponding to modest increases in temperature, for removing bubbles from the surface before they grow significantly or coalesce with neighboring bubbles, and for ensuring adequate liquid replenishment. The report considered the use of ISS for performing some of the long-term research that had been recommended. Although multiphase flow and heat transfer could be performed on the Shuttle, the ISS offers an ideal opportunity for these types of experiments because sufficient power would be available.
The benefits of the microgravity research that can be provided by the ISS "laboratory" include, but are not limited, to advancement of fundamental knowledge of complex phenomena and processes, design and operation of various engineered systems (e.g., for power production, fluid and thermal management, environmental control, etc.) for exploration and development, and development of new materials and processes.

The Task Force Analysis

The Task Force ranked the thrusts in this theme area as follows:

- **Technologies for Propulsion and Power Systems:** Priority 1. Propulsion and power should be ranked first for enabling exploration of the Moon, Mars and planetary bodies outside the solar system. Without advanced propulsion systems and power sources, human exploration beyond LEO (Mars) will be impossible. Advanced propulsion systems are needed to reduce the duration of flights to other planetary bodies. An example of such a propulsion system is the magnetoplasmadynamic rocket that accelerates charged particles using magnetic fields. The magnetic field interacts with the gas to accelerate gas particles, thereby creating rocket thrust. Hydrogen, lithium or argon can be used as propellant gases. NASA jointly with the space agencies of Germany, Japan and Russia are developing other advanced propulsion systems. Electric power needed by the spacecraft is generated by photovoltaic fuel cells, as is the case in ISS, and comes from incident solar radiation, but for long-duration flights, beyond Mars, solar irradiation will be inadequate because of increasing distances from the sun, and other energy sources will have to be developed for use.
- **Fire Safety and Fluid Systems Engineering:** Priority 2. Although an initial and acceptable fire safety system has been implemented on ISS, there are still some very fundamental combustion and fire safety issues that need to be addressed to improve fire safety for the crew. For example, gravity effects in smoldering, as in the case of electrical cable fires, is a fire safety issue that needs to be addressed as there could be production and propagation of hazardous or flammable products that could impact fire and crew safety in a spacecraft.

- **Radiation Protection:** Priority 3. Radiation protection is primarily an engineering issue (solution). New materials and techniques for radiation shielding need to be developed for long-duration human exploration beyond LEO, but radiation protection, as opposed to radiation health, is less critical as a fundamental research priority. It should be noted that much of this research could be done in ground-based facilities.
- **Mission Resource Production and Robotic Exploration:** Priority 4. A long-duration mission to Mars would require production of resources such as oxygen, or propellants from the Martian regolith. Without proven in-situ resource utilization and processing systems, long-duration human exploration of Mars will not be possible. However, other alternatives are available for initial, short-duration exploration concepts. A number of mission resource production concepts have been advanced and ISS could provide a platform for testing the technologies.
- **Biomolecular systems technology and sensors**: Priority 4. In spite of the fact that such technology and sensors may be very relevant to NASA's mission in space, for improving the health and safety of humans living and working in space, with limited resources NASA cannot effectively compete with the private sector and agencies such as DARPA and NIH, who are already funding research in this area. It should be noted that this research is performed in ground-based facilities.

D. Research Integration Division

D.1 Commercial Applied Sciences
D.2 Commercial Engineering Research and Technology Development

Space commerce as a national goal is written into US law. P.L. 98-361 (1984) "declares that the general welfare of the United States requires that the National Aeronautics and Space Administration seek and encourage, to the maximum extent possible, the fullest commercial use of space." The 1998 Commercial Space Act (P.L. 105-303) "declares that free and competitive markets create the most efficient conditions for promoting economic development, and should therefore govern the economic development of Earth orbital space." Therefore, the Task Force recognizes that the 1998 Commercial Space Act established as public policy the commercial use of ISS and NASA's role as a facilitator to utilize ISS for commercial purposes.

The Task Force also recognized that it is not appropriate to apply entirely the same research merit criteria to the Commercial Applied Sciences and Commercial Engineering Research and Technology Development themes as were developed for Fundamental Biology, Bioastronautics and Fundamental Microgravity. The Task Force did assign priority ratings to the commercial areas and did use the research merit criteria, but the programs are also evaluated by other review committees, using additional criteria appropriate to commercial activity.

These differences arise from the basic concept upon which the commercial programs are structured, as compared to the science programs. Commercial program priorities are established in response to private sector interest and investment. Such priorities are dynamic in nature and can change as a function of the market's perception of value of the space research product. Additionally, commercial space research reflects the competitive advantage envisioned as a return on the investment being made in space research activities.

From a macro-perspective, commercial space research activity contributes to national economic growth through increased flow of improved products and services. This in turn contributes to the GNP, to the strengthening of human capital, and in fostering new generations of skilled workers. These factors provide the justification for NASA's role in mitigating, but not eliminating, the high risks presently confronting the commercial sector in regard to supporting space research as a venue for private investment and product development.

The availability of ISS as a permanent presence in space will go a long way toward ameliorating the risk factors faced in the past. Thus, it is reasonable to expect that as the current R&D projects transition into the marketplace as commercial products and services, the need for NASA subsidized funding will decrease and eventually disappear.

D.1 Commercial Applied Sciences

Description
In partial fulfillment of its commercial mandate, NASA established the program now identified as the Commercial Space Centers (CSC's). The centers were established following competitive, peer-reviewed procedures in 1985, 1986, and 1987. Subsequently, some of these centers were terminated and

others were competitively added. The research area of each center was defined in the proposal submitted for the competitive peer-reviewed evaluation. One criterion used in these evaluations was whether the proposal represented a high priority research area as defined by NASA and other organizations involved in identifying space research needs. The fundamental premise on which the CSC's function is based on industry-driven research. Consequently, specific investigations at the Centers are defined and conducted jointly by industry and center personnel.

Current research thrusts in the CSC's include biotechnology (primarily space-based macromolecular crystallography), agribusiness, and advanced materials development and processing.

Commercial investigations, in many cases, require long-duration experimental times as can only be provided by ISS. In addition, commercial research requires repetition or iteration of the experiments so as to confirm results of previous experiments. This is particularly important to a commercial organization that is using the space investigations in their development of a new product or service. The commercial investigations utilize hardware developed specifically to minimize, but not exclude, the need for ISS crew intervention to complete the experiment protocol.

Meta-Analysis of Previous Reports and Recommendations

Commercial Space Centers are reviewed on approximately a 3-year time frame. The review teams included members with technical expertise in the area specific to the research being conducted at the center, and members with financial expertise to verify the commercial and business potential of the joint industry/academia research program. Those reviews considered most relevant for the Commercial Applied Sciences were:

- *A Review of the Centers for the Commercial Development of Space; Concepts and Operation,* NAPA, 1994
- *The International Space Station Commercialization Study,* Potomac Institute for Policy Studies, 1997
- *Reflections on the Commercial Space Center (CSC) Program,* NAPA, 1998
- *NASA: Commerce on the International Space Station,* KPMG Report, 1999
- *Future Biotechnology Research on the International Space Station,* NRC, 2000
- *X-ray Crystallography Facility at the Center for Biophysical Sciences and Engineering,* University of Alabama at Birmingham, prepared by an external review panel commissioned by NASA management, 2000

All these reviews acknowledged that the research conducted in the Commercial Applied Sciences, identified as 1) Biotechnology, 2) Agribusiness, and 3) Advanced Materials, was based on scientifically accepted methodology and reflected areas of economic interest to the industry partners. The reviews recommend that the industry partners place greater emphasis on increased financial commitments. These reviews also pointed out that the long-lead times involved in the realization of return on investment by the industry partner, unpredictable scheduling of space access for the research, and high integration and launch costs all present significant negative impacts on how much of an industry financial commitment is made at this stage of the space program.

NASA's commercial program has supported the development of many different types of apparatus for macromolecular crystallization experiments on Space Shuttle and potentially on ISS. All require minimal crew intervention and several have had extensive flight-testing. Crystallization techniques that have been investigated include passive and dynamically controlled vapor diffusion, gel diffusion, and liquid-liquid diffusion. Devices for examining crystal nucleation by laser light scattering and phase-shift interferometry have also been developed.

The members of the NRC Task Group were impressed by the prototype XCF (X-ray Crystallography Facility) and recommended that it be further developed for flight on ISS. It is an integrated, highly automated system, which includes crystal growth, remote microscope inspection and selection, crystal cryo-preservation and storage as well as the possibility of limited on-site x-ray diffraction studies. The XCF allows for the handling of large numbers of samples and may permit iterative experiments. Cryo-preserving fresh crystals on-site was deemed by the NRC task group to be essential. The XCF evaluation panel rated this capability at a priority higher than that of obtaining diffraction data in orbit.

NASA has been successful in building a community in crystallization. Space missions have involved small quantities of materials and relatively simple apparatus. This program might be a model for the other focused areas of technology development, which are less mature. However, the slow turn-around time in space is a major issue for commercially viable research. This is a problem that NASA must address.

The Task Force Analysis
This program addresses the national commitment to develop the commercial potential of space. Some Task Force members expressed a concern that the results emanating from such investigations may not be justified on a cost/ benefit basis. However, in view of the nature of access to space in the past that negatively impacted opportunities for commercial and science research, it is not possible to make an accurate cost/benefit analyses at this time. Many of these negative impacts will be eliminated with the availability of ISS and this should allow for the conduct of effective cost/benefit analyses in the future. There is an historical analogy with commercial use of synchrotron facilities for diffraction studies. After the usefulness of the latter technology was established and the government committed to the construction of very expensive third-generation synchrotrons, a large number of pharmaceutical and biotechnology companies made an ongoing investment, now in excess of $20 million, to build beamlines.

The Task Force rated the three areas as follows:

- **Biotechnology:** Priority 3. Although there is demonstrated success in building a commercial user community and in the development of advanced technology for microgravity crystallizations, some task group members expressed doubt about the commercial viability of the program. However, there is a counter argument in the commercial participation in the building of synchrotron beamlines. The combination of better ordered crystals from microgravity, cryo-preservation and the use of synchrotron radiation can all be expected to contribute to the higher resolution diffraction data which will be crucial in many structural studies. It is important that this program attempt to resolve the issue of whether the microgravity environment can be a valuable tool, therefore the Task Force endorses the NRC recommendation: *"NASA should fund a series of high-profile grants to support research that uses microgravity to produce crystals of* *macromolecular assemblies with important implications for cutting-edge biology problems. The success or failure of these research efforts would definitely resolve the issue of whether the microgravity environment can be a valuable tool for researchers and would determine the future of the NASA protein crystal growth program."*[6]

- **Agribusiness:** Priority 4. Areas of research include enhanced gene transfer in microgravity and gravitational effects on plant structure and composition. The concern is that the value of the research may not justify the costs associated with accessing the microgravity environment.
- **Advanced Materials:** Priority 4. The consensus was that the activity described as requiring ISS for measurement of thermophysical properties of alloys and the zeolite crystal research may represent viable commercial space activities. The other areas may be of questionable commercial value when compared to the cost of access to space. Other activity appears to require additional ground based experimentation prior to being considered for scheduling on the ISS.

D.2 Commercial Engineering Research & Technology Development

Description

A core characteristic of this program is that all of the testbeds and instruments are developed with private funds. NASA's commitment to the commercial partners is both availability of the attach point on the ISS and a carrier that allows transport up and down, plus required crew time for attachment and servicing. The carrier is being planned under an international partner arrangement with Brazil. NASA's goal is to advance the program to the point where the industry partner bears the full cost of the ISS access and utilization. Investments are being made by both large and small companies in remote sensing and automated imaging systems; telecommunications; thermal control; power generation, storage and distribution; robotics and structures; and propulsion.

Virtually the entire Commercial Engineering Research & Technology Development program will be conducted using the external (non-pressurized) pallets and truss of the ISS. The ISS offers the advantages of an ability to access and service the equipment on a regular basis in order to examine the experimental results, reconfigure the testbed, and retrieve the experiment. Crew time is involved only during the time the experimental unit is being attached to ISS and when it is retrieved. During other times the experimental unit would function autonomously.

Meta-Analysis of Previous Reports and Recommendations

The commercial aspects of NASA's program for engineering research and technology development on ISS are derived from the report:

- *Engineering Research and Technology Development on the Space Station*, NRC, 1996

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[6] *Future Biotechnology Research on the International Space Station*, Space Studies Board, National Research Council, 2000. page 8.

The report emphasized that reducing costs and improving performance of future government and commercial activities in space will require continuing engineering research and technology development (ERTD). Some other conclusions of the report are:

- The ISS will be a valuable location for in-space ERTD
- A major goal should be to reduce operations and maintenance costs of the ISS through infusion of new technology
- NASA should determine which modifications of the ISS to support ERTD should be given a high priority
- A pilot program using multidisciplinary expert review to help companies develop and commercialize new technologies should be considered
- A roadmap for ERTD on the ISS should be developed that links NASA with other agencies, academia, and industry
- NASA should establish a single organization to work with researchers interested in conducting ERTD experiments on the ISS and other space platforms
- ERTD on the ISS should promote the education of the next generation of scientists and engineers.

The Task Force Analysis

The six commercial research areas were assigned, as a group, a priority score of 2, largely because the amounts of money being invested by the private partners are substantial. The rationale for assigning the same priority score to all six of the research areas was that industry commitment in the area of interest is based on what the company perceives as the Net Present Value of the resulting product. Additionally, since the research is proprietary, it was not possible for the Task Force to review it in any depth. It was decided that industry should set the priorities based on their willingness to invest, and that a further differentiation in priorities would be inappropriate.

The Commercial Engineering Research & Technology Development (ERTD) effort that has been developed is based on the cooperative inputs of both industry and academia. The program responds to six of the nine recommendations given in the NRC report. All of the identified ERTD areas require the space environment to determine the long-term effects on the systems being evaluated for use in space. Industry participants consider the ISS a highly desirable testbed because it allows for regular access and reconfiguration or replacement of an experiment or subsystem as the results may indicate.

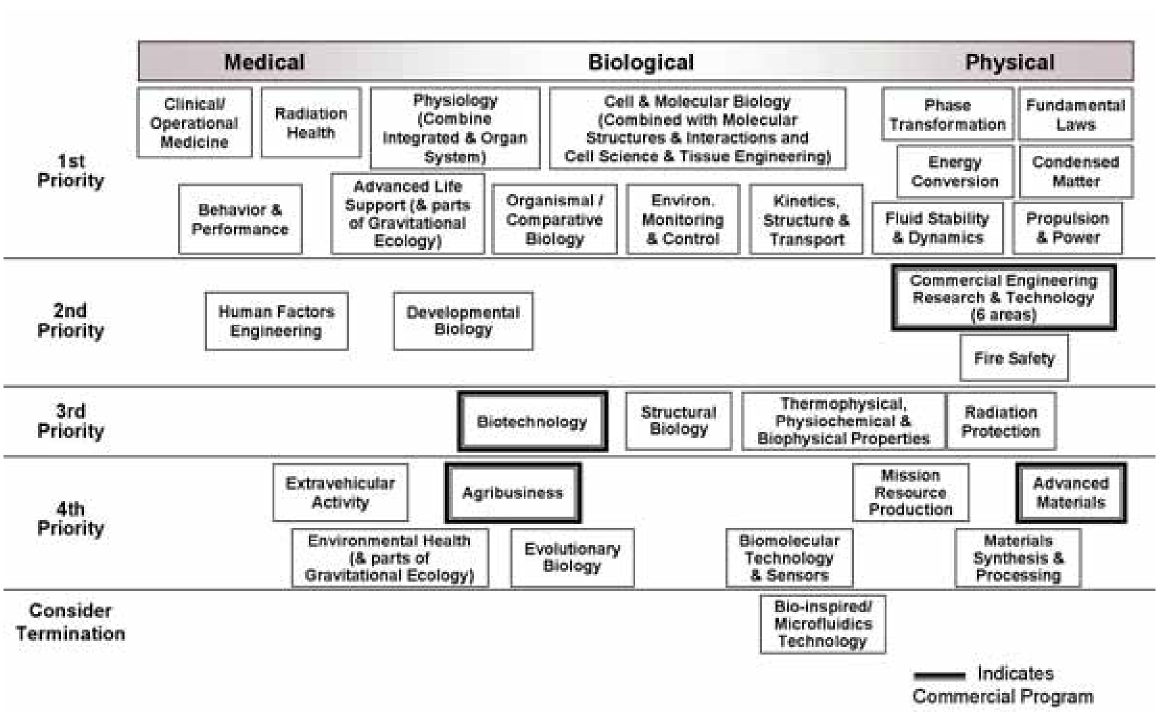
2.2 Task Force Priorities across OBPR Divisions

Basis for prioritization of research across OBPR Divisions

- Reports by hundreds of expert opinions outside NASA involving many hours of review of individual research projects within NASA divisions from (see Appendix D).
- NASA-presented background on the program
- The merit criteria developed by OBPR and modified by ReMAP were used to evaluate research within the 4 OBPR divisions (see Appendix K).
- Rationale for prioritization articulated by the Task Force as important discriminators in determining the priority assignments across the entire OBPR portfolio (see Appendix L).

Interpretation of priority rankings: The assignment of priorities by ReMAP (shown below) was done at the level of OBPR research themes and not at the level of individual research projects.

- The ranking of priority 1 to a given theme area constitutes our statement that there are very important research questions within this research theme, and does not suggest a blanket endorsement of all the projects within an area.
- Prioritization within each research theme requires the evaluation of specific research projects and productivity of individual Principal Investigators. This effort was outside of the scope of ReMAP.

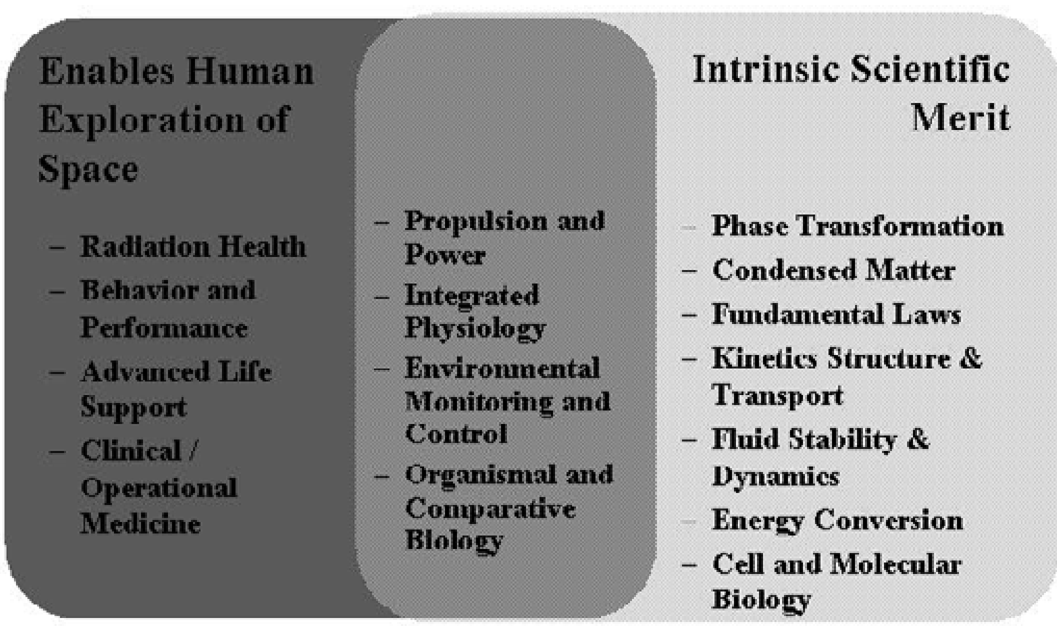


Final Task Force cross-theme ranking of research priorities for OBPR

High priority research falls into two categories

The high priority research identified by the Task Force falls into two broad, sometimes overlapping goals.[7]

- Addresses questions of intrinsic scientific merit (including those which might improve the human condition on earth) that cannot be accomplished in a terrestrial environment:
- Obtains information necessary to enable human exploration of space beyond low-earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment.
- Some research contributes to both goals.



Categories of Highest Priority Research
[This schematic does not imply strict adherence of projects to a specific category.]

The Task Force wrestled with the question of whether any further prioritization was possible; in particular, whether it is currently possible to place one of these broad goals at a higher priority than the other.

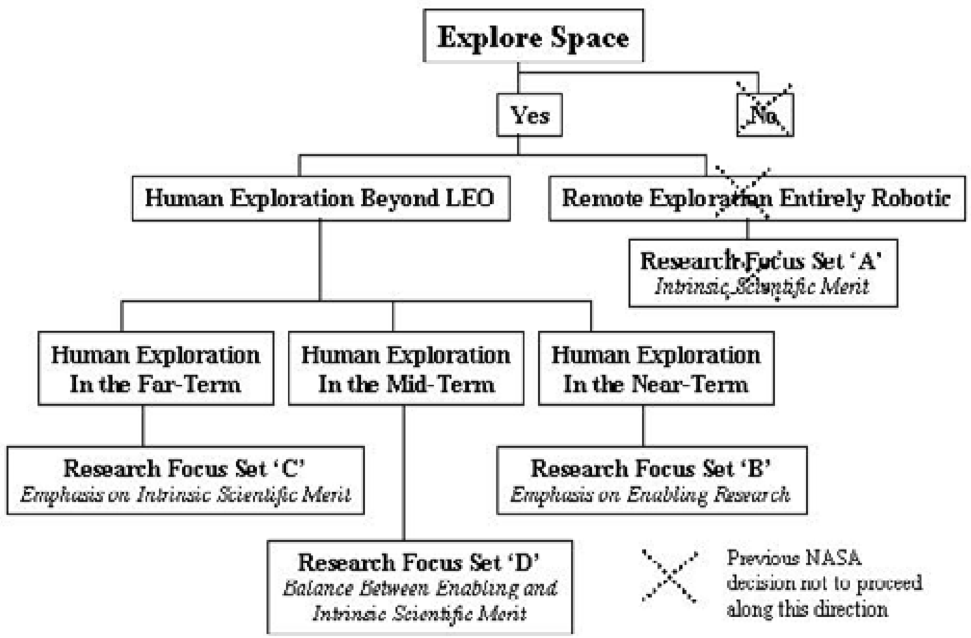
In the history of the United States space program both broad goals have been important, though their relative importance has changed over time. The limited amount of biological and physical research that occurred during early space exploration, particularly the Apollo era, focused on the health and safety of astronaut crews in a microgravity environment. Significant research questions that did not contribute directly to a successful moon landing received lower priority. In contrast, more regular access to space provided by the Shuttle afforded an opportunity for "basic" research to take higher priority. The expansion of space-based research in the physical and biological sciences over the past twenty years is a testament to this fact. This suggests that

7 Excluding commercial program, which is of a fundamentally different nature

one goal can receive higher priority over the other, but this ranking may shift depending on the programmatic needs of NASA at any particular point in time.

The Task Force recognizes the ISS is a truly remarkable facility that can be used to tackle either broad goal. However, the Task Force also believes that, while NASA's new Vision and Mission clearly articulate human exploration beyond LEO at some point in time, it is not yet known when such exploration might take place.

A possible decision tree, reflecting programmatic decision points that would affect research priority outcomes is shown in the figure below.



Decision Tree: Programmatic Decisions Affecting Research Priorities

Fine tuning of order of carrying out highest priority research thrust areas requires knowledge of time frame for future long-duration human exploration, This dictates which agency goal (enabling human exploration of space or answering questions of intrinsic scientific merit) takes precedence in the era of the ISS.

If a decision were made to develop a near-term human exploration mission, NASA's research would necessarily have a strong emphasis on solving the numerous challenges to further human exploration on an accelerated schedule (Focus Set 'B'). However, if further human exploration were deferred to the very long term, research of intrinsic scientific merit and the sub-set of enabling research specifically to improve the efficiency and capabilities of the ISS and the health of its crew would take precedence (Focus Set 'C'). Focus Set 'D' would be a balance between work of intrinsic scientific merit and research to enable the next generation of human exploration missions, allowing NASA to keep open the option of further human exploration in the not-too-distant future.

Once the NASA time frame for human exploration of space is determined, research priorities that solve near-term problems can be distinguished from those that solve very long term problems. Because the deciding factors for the next step are programmatic, rather than scientific in nature, the Task Force did not attempt further prioritization.

2.3 Findings on Science Productivity in OBPR and on the ISS

Historic View of Prioritization

- Context for Development of OBPR Research Program
  - The OBPR research programs evolved in the absence of stable budgets and predictable flight access.
  - Prioritization of research questions of OBPR has not been possible in this context.
- Previous External Reports
  - NASA's Space Research Program has been reviewed many times.
  - Consecutive reports have generally reached the same major conclusions.

OBPR Research Platforms

- The OBPR research program includes elements that:
  - Require ISS
  - ISS is optimal but not necessary
  - Can be addressed using the Shuttle
  - Can be addressed using free flyers
  - Can be addressed in ground-based research

ISS Capabilities

- Unique Research Capabilities of the ISS:
  - Long duration flight with
    - Humans to perform experiments and operate equipment
    - Humans as subjects
  - Reasonable time frame for iterative studies:
    - Frequent access
    - Experiment repetition
  - State-of-the-art on-orbit laboratory facilities

ISS Biological Research Needs a Centrifuge

- The Task Force encourages expedited development of the centrifuge with appropriate external review and guidance to ensure timely deployment.
- The ISS centrifuge serves two essential research functions in the biological sciences:
  - It provides a rigorous in-flight control condition with a centrifugal field where gravity-driven forces can act, and
  - It produces a variable gravity field to identify threshold-loading conditions that might facilitate biological processes.
- Engineering aspects of the centrifuge are largely resolved
- Current engineering analysis indicates that the centrifuge will not violate ISS microgravity requirements.
  - If necessary, centrifuge use could be scheduled to eliminate (currently unforeseen) interactions with other experiments.

OBPR Organization

- OBPR organization, program structure, and solicitation mechanisms:
    - are based on research discipline,
    - lack a strategic approach,
    - are not optimal for identification and implementation of high priority/high impact research.
- Strategic approach may identify:
    - Expected outcomes
    - Roadmap to achieving goals
    - Most effective organization to achieve goals
    - Appropriate mechanics for solicitations
    - Appropriate modes for research (e.g., team approach or single investigator)
    - Need for sunset condition on research projects

Need for Commercial Research

- Public Law 105-330 establishes as public policy the commercial use of the ISS, and NASA's role in facilitating this use.
- The Task Force used the research merit criteria developed.
- Evaluation of the commercial programs required additional criteria appropriate for commercial activities. These include:
    - private sector interest and investment,
    - national economic priorities, and contributions to economic growth.

Optimizing Research and Education

- The cadre of high caliber participating scientists is too small because
    - The lack of predictable, frequent, and timely access to flight opportunities limits interest from the research, commercial and educational sectors, and
    - Research programs lack a stable funding base.
- Education of the next generation of scientists and engineers suffers because
    - Graduate and postdoctoral students are constrained from participating in NASA research by unpredictable flight opportunities with intervals often exceeding students' time in training

OBPR Implementation

Preliminary Implementation Analysis of 1st and 2nd Priority Research

- Most of the ReMAP research priority findings were established at ReMAP Meeting #2.
- OBPR preliminary ISS implementation analysis was conducted following meeting #2 and was based on these interim Task Force research priority findings.

Preliminary OBPR Implementation Analysis Suggests that at US Core Complete and at US+IP Core Complete capability to do high priority research is limited:

- Crew time and upmass places constraints on the amount of high priority research that can be addressed.
- Commitments to International Partners exacerbate the problems of adequate crew time.
- Some OBPR research of scientific and/or commercial importance can be accommodated on platforms other than ISS.
- Several hardware components critical to high-priority research investigations are not funded in the current OBPR budget.
- Availability of powered middeck lockers is not sufficient to meet nominal requirements of high priority research.
- At a Shuttle flight rate of 4/year, there is inadequate accommodation for delivering mass to orbit for research.

3.0 Recommendations

Framework for Recommendations

The charge to ReMAP by the NASA Administrator, echoed by the OBPR Associate Administrator, was that ReMAP should concentrate efforts on prioritizing the existing research programs within OBPR. (Also refer to Appendix A, Terms of Reference, 1st paragraph.) In order to do this, ReMAP considered as fully as possible the extensive background of reviews and reports to NASA addressing space research priorities.

- ReMAP performed its prioritization analysis without regard to budget or facility constraints, and recommends the resulting set of priorities for OBPR research to NASA to inform current and future implementation decisions and guide future program development.
- ReMAP was informed of the extent to which NASA can address these research priorities, given the current budget, and current and planned ISS facilities and capabilities. This information did not affect the priorities identified.

3.1 Science on ISS

If enhancements to ISS beyond "US Core Complete" are not *anticipated*, NASA should cease to characterize the ISS as a science driven program.

Rationale:

- OBPR's implementation analysis suggested difficulties in implementing the high priority research given the current and near-term plan.
    - Crew time, resupply upmass, and facilities are major factors.
- Other reasons for ISS include engineering achievement, space commercialization, international leadership, and classroom education.

3.2 ISS Research Productivity

NASA must resolve the upmass and crew research time issue.

Rationale:

- Crew time and upmass were identified as presenting significant restrictions on research productivity under both US and US + IP Core Complete configurations.
- IP barter agreements are based on research that requires greater than a 3-person crew.
- ReMAP understands that NASA is examining crew time availability for research and encourages vigorous attention to this critical resource.

3.3 Current ISS Productivity

As ISS nears completion, NASA should increase science priority and productivity on ISS.

- For each ISS increment, designate one crewmember as the "science officer."
  - The science officer will be the primary crew person to participate in payload training.
  - At least 1/3rd available crew time (assumes a three person crew) should be dedicated to science operations.
  - Other crewmembers also participate in science operations.
- Upmass allocations must support the ISS crew conducting scientific investigations.
  - If this cannot be accommodated on assembly or logistic flights, add a Shuttle flight to the manifest that will bring only science payloads to ISS.

Rationale:

- Currently, science is not a priority for the limited crew time and upmass available for ISS.

3.4 Basic Research

OBPR should include, in its high-priority research portfolio, outstanding basic scientific research programs that address important questions in the physical and biological sciences, and which require long-term experiments on the ISS, based on their intrinsic scientific value.

Rationale:

- OBPR's research portfolio must be built around the most important scientific problems relevant to the NASA mission on the ISS, rather than covering representative sub-fields of science.

3.5 Implementation of ISS Research Facilities

NASA should ensure appropriate funding for implementation of high priority facilities, such as the habitats and centrifuge.

Rationale:

- A number of facilities required to perform the highest priority biological and physical sciences research are currently un-funded or delayed.
- Essential understanding of the full range of effects of gravity on life will require:
  - Appropriate plant & animal habitats
    - Either as previously planned or acceptable alternatives
    - Essential to perform the research
  - Centrifuge capability needed to
    - Identify threshold loading conditions
    - Validate preliminary findings suggesting a role of microgravity where controls (assessment of other factors related to ISS conditions) could not be analyzed.

3.6 Fully Utilize Available Options for Space Research

NASA should consider additional Shuttle science/commercial flight opportunities.

- Investigate dedicated science and/or commercial flights on a regular basis.
    - Guarantee flight opportunities
    - Guarantee routine, repetitive access to space
- Investigate the possibility of auctioning rack space to gauge true market interest.

<u>Rationale:</u>

- Many science priorities do not need long duration in space.
- Many science priorities do need repetitive, routine access to space.
- NASA funding may impact market interest.
- Use of non-NASA funds to purchase a flight opportunity can be used as another indication of the value of the proposed space research.

3.7 Time to Orbit

NASA must reduce the time between experiment selection and flight for research investigations.

<u>Rationale:</u>

- Current long lead-time discourages excellent researchers from proposing to NASA's programs.
- "Time to orbit" is a major commercial partner concern.
- Reasonably short times are essential if graduate students are to be involved.

3.8 Research Funding

In order to attract high caliber scientists from a large national pool, NASA must assure science as a priority commitment with regard to flight schedule and project funding.

<u>Rationale:</u>

- Research funds have been diverted a total of 4 times to cover engineering overruns.
- Office of Space Flight indicated total research slippage for investigators has been as much as 4-5 years.

3.9 Methods for Research Solicitation

OBPR should consider alternative methods for research solicitation and recruiting of key performers.

<u>Rationale:</u>

- Solutions for OBPR's goal-oriented, need-driven research problems may be facilitated by alternative methods of solicitation and recruiting.
    - Project selection by peer review
        - A consensus based approach
        - Works best for individual PI science programs
        - Works best for broad focus, science community driven

- DARPA-style program management
  - Can open new areas
  - Serves to build communities
  - Can support multi-investigator projects
  - Works best for goal-oriented research

3.10 Increase Cadre of OBPR Investigators

OBPR must develop mechanisms to increase the quality and cadre of scientists participating in its research programs.

<u>Rationale:</u>

- More young and active investigators from top research institutions should be recruited to work on NASA's high priority questions.
- The Task Force felt the investigator community should be larger and more diverse.

3.11 Science Leadership

OBPR scientists should ensure the development of a visionary strategic research program that is focused on the problems whose solutions will further the NASA mission.

<u>Rationale:</u>

- Development of a strategic, goal-oriented program will enable selection of the best research to facilitate space exploration and fundamental science.

3.12 OBPR Organization and Process

OBPR should consider interdisciplinary organization and program structures aligned along research questions rather than discipline.

<u>Rationale:</u>

- OBPR is currently organized by discipline.
  - Tends to solicit by discipline, generally single investigator research proposals.
- Alternative organization could be more flexible.
- Many of the high priority questions are interdisciplinary in nature.
  - OBPR programs would be more productive if microgravity physics and life science programs were integrated.
- Different kinds of research require different structures (e.g., team approach vs. single investigator).

3.13 Coordinating Research Efforts

OBPR life sciences strategy should integrate multiple levels of analysis, (i.e., organismal, systemic, cellular, molecular).

OBPR physical sciences strategy should coordinate the research efforts from Fundamental Microgravity, Engineering, Commercial Engineering, and Technology Development where it makes sense. Examples: combustion and fire safety.

<u>Rationale:</u>

- Coordinated strategies focused on specific problems would optimize research productivity.

3.14 Potential New Lines of Research

OBPR should examine potential lines of research outside of the current research portfolio.

Rationale:

- ReMAP Task Force prioritized only the current research portfolio.

3.15 Metrics

Given that NASA has multiple requirements for producing and reporting productivity metrics, the purpose of each metric should be clearly delineated such as science productivity, education outreach, and public affairs.

Rationale:

- Specific metrics, even when accurate, do not necessarily index the measure of interest. For example, media attention is not suitable for evaluation of scientific quality.

3.16 Coordination with International Partners

NASA should continue coordination of facilities development and research solicitations with the International Partners (IP), and attempt to address the IP concerns.

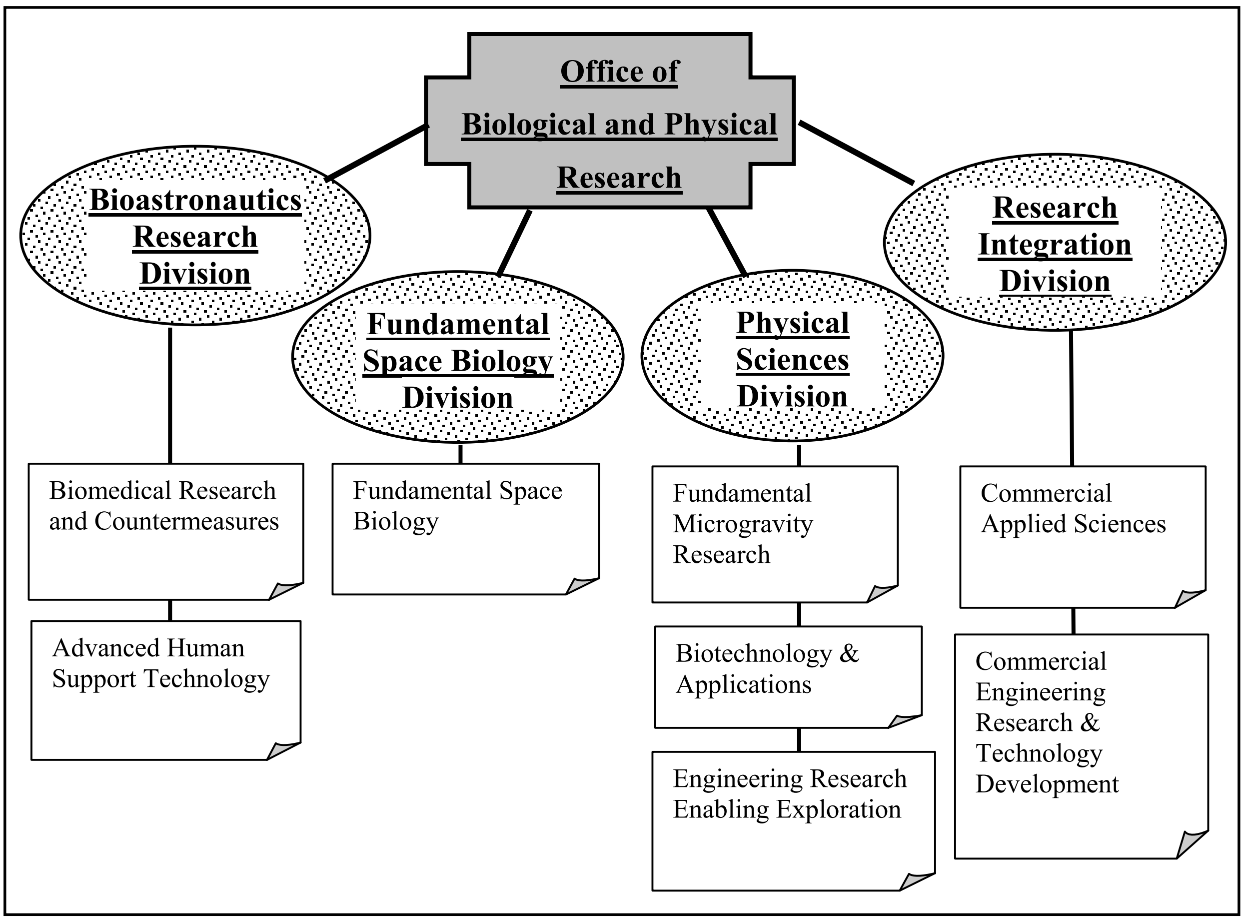
Rationale:

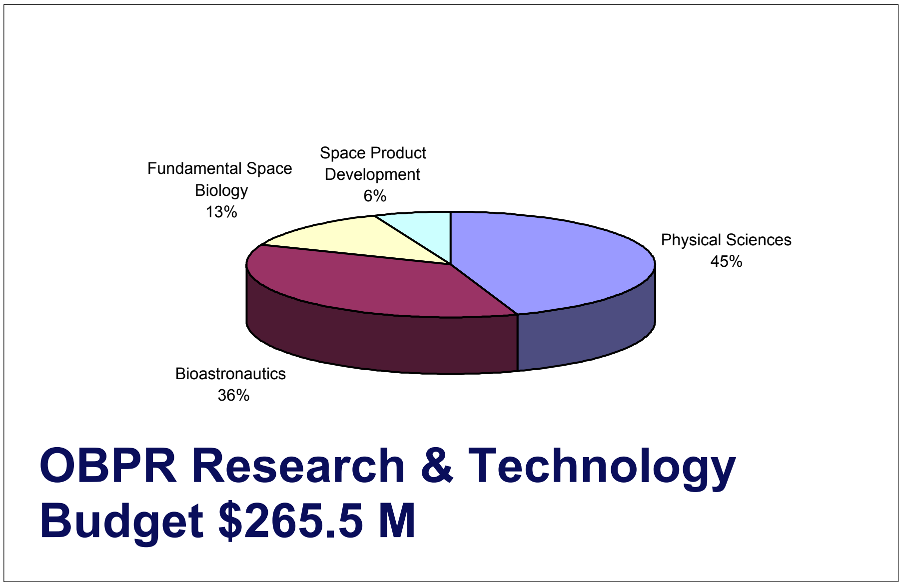
- The IPs have chosen to build certain ISS research facilities and not others to avoid replication based on understanding of shared facility utilization.
- IPs have continued interest in coordination with NASA and submitted analyses of their priorities and concerns to ReMAP.

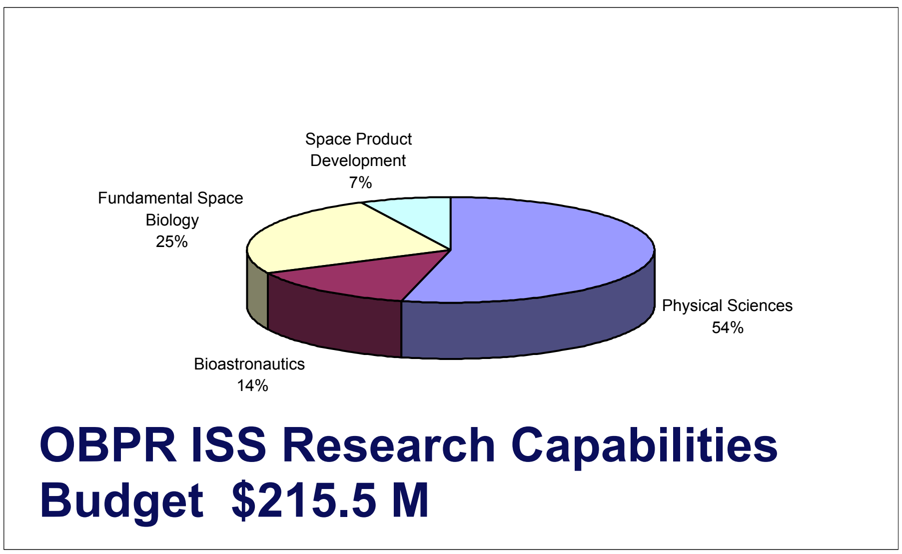
4.0 ReMAP Organization and Process

OBPR Divisions and Research Thrusts
NASA presented the research of the 4 Divisions of the Office of Biological and Physical Research (OBPR) to the Task Force as comprising 8 primary theme areas, integrated organizationally as shown below.

- ReMAP Task Force members focused their activities on their areas of expertise. The expertise of Task Force members is shown on the list of panel members on page 42.



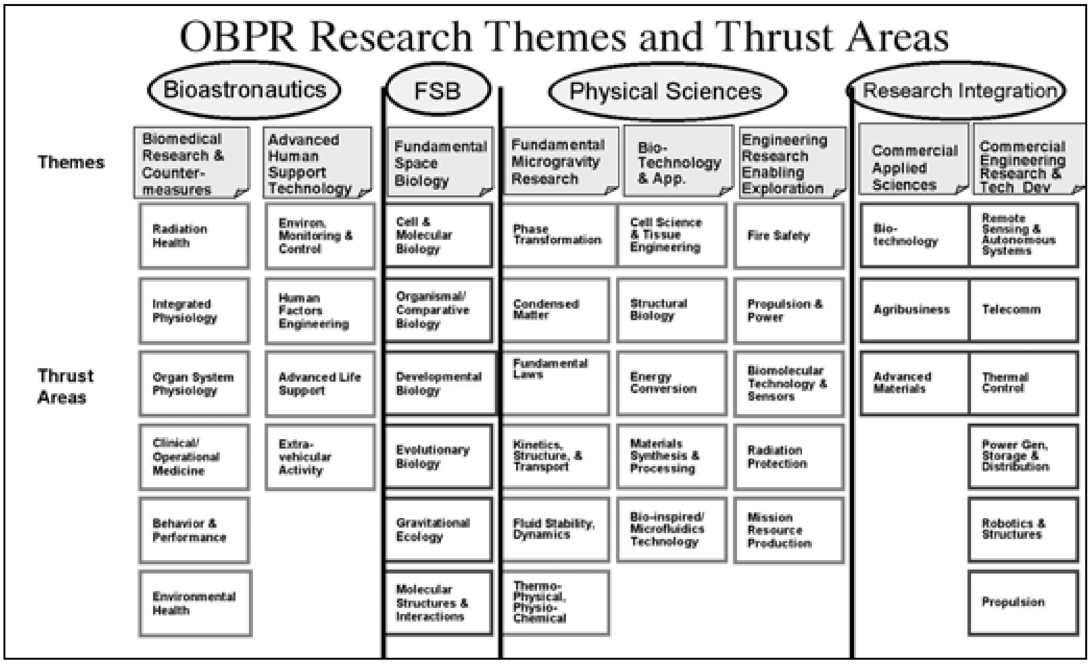




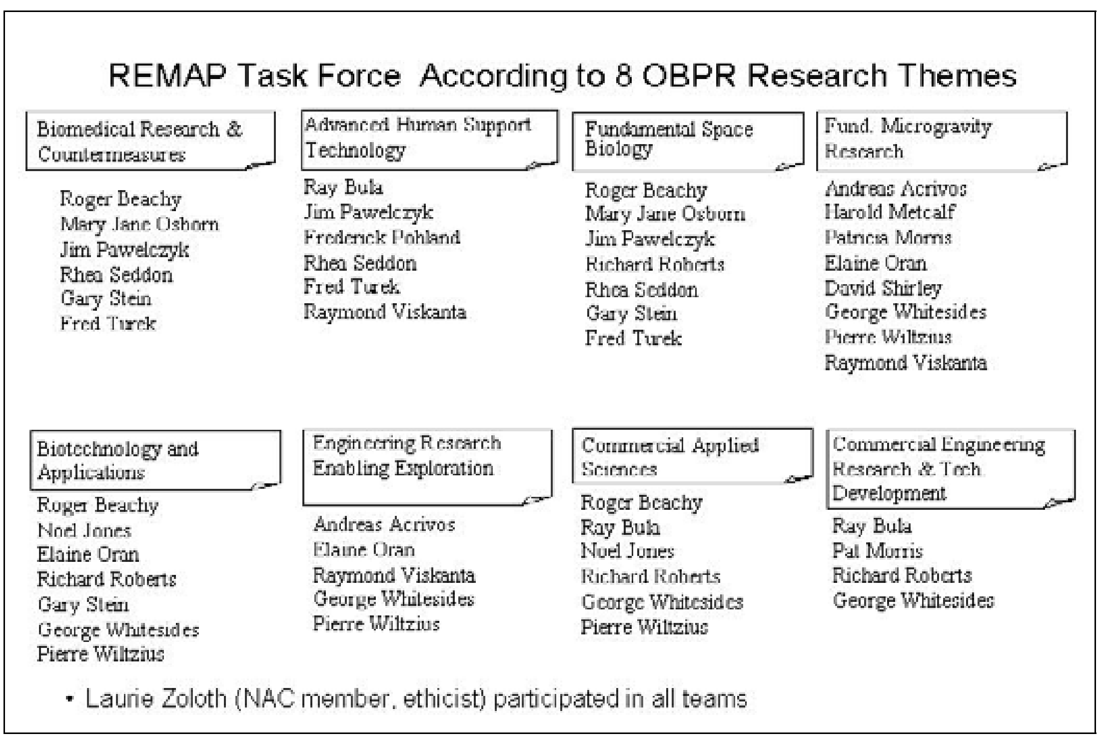
Relationship of ISS Budget to OBPR Budget

- The OBPR Research and Technology budget is a separate Enterprise allocation within NASA.
- The Congressionally mandated annual budget for ISS includes the OBPR ISS Research Capability Budget that supports the research hardware development.
- ReMAP did not review budgetary issues, though it did note where there were gaps in the implementation of high priority research (i.e., plant and animal habitats).
- OBPR research funding includes ISS-based research as well as research implemented on the shuttle, and the ground. ReMAP did not review this level of budget detail when deliberating the research areas.

Alignment of Task Force Expertise with OBPR Divisions and Research Thrusts
NASA presented the research of the 8 theme areas as comprising 3-6 "Research Thrusts" integrated organizationally and programmatically, as shown below.



To best use Task Force expertise to prioritize research, members broke into Discipline teams according to their self-identified expertise in each of the 8 Research Themes, as follows:



Prioritization within and among research themes:

- The OBPR program background, objectives, and descriptions of the research thrusts and theme areas were provided to the Task Force.
- OBPR developed a proposed set of criteria for evaluating OBPR research programs and presented this to the Task Force at the first meeting. These criteria were vetted by the Task Force and were agreed to be an appropriate starting point for evaluation of research priorities. The Task Force incorporated all of the above into their prioritization process, but went a level further in deciding the final priorities. Additional considerations for distinguishing between high, medium, and lower priorities were articulated by the Task Force (see Appendix L, ReMAP Prioritization Criteria and Justification).
- Each Disciplinary Team established priorities and presented their rationale for prioritization to the full Task Force for discussion. This included presentations by individuals or small groups within the Team summarizing the Task Force perspective on previous reviews and recommendations ("meta-analysis") of NASA's space research program in the theme area.
- Once within-theme priorities had been identified, the Task Force, as a body, analyzed the results across theme areas and developed a set of science-driven priorities for OBPR research.

The Task Force analysis was performed without regard to ISS facility constraints, in keeping with instructions from the Administrator.

- Following the establishment of priorities, ReMAP was provided with an analysis of the extent to which NASA can address the research priorities given the current and planned ISS capabilities. This information was not independently evaluated by ReMAP. While it did not affect ReMAP priorities, it was taken into account in the findings and recommendations.

The Task Force was charged to identify the best science that could be done by OBPR on the ISS and other platforms, and used the information made available in reports from previous review committees available for each of the OBPR divisions.

- The Task Force limited its analysis to the existing OBPR research portfolio.
- The Task Force noted the unique features of ISS (human tended, long duration [> 1 month], exposure to microgravity) and identified research that can only be conducted on the ISS.
- The Task Force noted that each OBPR division had been reviewed frequently and recently. Importantly, serial reviews of each division were consistent in their findings and recommendations lending confidence to ReMAP conclusions based on this information.

The Task Force process for prioritizing the research program of OBPR and ISS was informed by

- The Terms of Reference (see Appendix A) describe the charge given to the ReMAP Task Force.
- The NASA Administrator's address to the group at the first and third meeting emphasized that the ReMAP Task Force should focus on defining the science research priorities without regard to budgetary and facility constraints.

Inputs to the Task Force

- **Structured Briefings**: Reviews of NASA vision and mission; OBPR research programs, priorities and criteria; background on the International Space Station; results of the International Space Station (ISS) Management and Cost Evaluation Task Force (IMCE) review; OBPR implementation analysis; OBPR science metrics presentation, Meeting with the International Partners (IP) and presentation to the committee by Peter Voorhees, Chair of the NRC Committee for Microgravity Research.

- **Formal Reports:** External research review reports (primarily studies conducted by the NRC) were made available to the Task Force. These previous reports played a key role in ReMAP deliberations. The committee received some of these reports from OBPR prior to the first meeting. Many more reports were made available to the Task Force as deliberations proceeded. The committee relied heavily on the expertise and time invested by hundreds of members of the scientific community in generating these reports. The analysis of previous reports contributed very significantly to the findings on research priorities and recommendations.

5.0 Appendices

APPENDIX A: Terms of Reference

These Terms of Reference establish the Research Maximization and Prioritization (ReMAP) Task Force of the NASA Advisory Council (NAC). The ReMAP Task Force is chartered to perform an independent external review and assessment of research productivity and priorities for the entire scientific, technological, and commercial portfolio of NASA's Biological and Physical Research Enterprise, and to provide recommendations on how to achieve the greatest progress in high-priority research within the President's budget request.

This task force will produce a final report that will focus specifically on the following items:

1. Evaluate and validate high priority science and technology research to be funded by OBPR to maximize the research return within the available resources in the President's FY 2003 Budget for OBPR and International Space Station (ISS).

2. Evaluate the major thrust areas and key research objectives for OBPR with an emphasis on establishing the research content for the ISS US Core Complete configuration.

    a. Assess how these key objectives can be addressed by the ISS relative to other means (e.g. ground-based research, free-flyers, Space Shuttle).

    b. Recommend how the ISS capabilities or other means could be used to best achieve high-priority research objectives.

    c. Given these major thrust areas and the results of item 2b, assess research content options consistent with the ISS US Core Complete configuration. Assess the extent to which each option allows for a viable evolution of the research strategy, given the possibility of research-driven enhancement to the ISS beyond US Core Complete.

    d. Recommend modifications and/or additions to the OBPR research goals and objectives.

3. Recommend ways to increase scientific productivity (e.g. automation, a non-governmental organization for managing research, etc.) and the metrics to measure productivity.

4. Recommend criteria that can be used by OBPR to implement specific research activities and programs based on documented priorities.

5. Identify areas for priority consultation with the international partners.

MEMBERSHIP

The NASA Administrator shall appoint the Chair and Members of the Task Force. The Chair shall be a nationally recognized science and technology leader with strong management and/or policy experience.

Membership will include recognized scientists and technologists from academia, government, and industry with expertise spanning diverse disciplines in biological and physical sciences. The membership will be between fifteen to twenty individuals with a distribution including researchers associated with NASA programs and scientists and technologists with no NASA program involvement. Members will be appointed as Special Government Employees.

MEETINGS

The Task Force will meet a minimum of three times in formal sessions and will also meet with support teams/subgroups when necessary.

REPORTING

The Task Force will present its findings and final report to the NAC at its June 2002 meeting. The NAC will consider the findings by this Task Force and formally present its recommendations to the NASA Administrator for an Agency response.

ADMINISTRATIVE PROVISIONS

The Executive Secretary will be appointed by the Administrator, and will serve as the Designated Federal Official. The Office of Biological and Physical Research will provide the staff support and the travel funds for the Task Force. The funding allocation is $300,000.

DURATION

The Task Force will complete its charter by June 2002. [NOTE: The NAC will deliberate at the June meeting and report out to the Administrator – similar to what was done with the IMCE task force.]

APPENDIX B: Biographical Sketches of Committee Members

Chair
Rae Silver, Neuroscience. Rae Silver is Helen L. and Mark N. Kaplan Professor of Natural and Physical Sciences and holds joint appointments at Barnard College, Columbia University, School of Arts & Sciences, and Department of Anatomy and Cell Biology at College of Physicians and Surgeons at the Health Sciences campus. She is also a member of the Program in Neurobiology and Behavior, which encompasses faculty in Neurobiology and Neurosciences campus-wide. Rae Silver received the B.Sc. at McGill University, Montreal Canada, and the Ph.D. at Rutgers University, Newark N.J. She has served on numerous research review panels, editorial boards of several journals, is a member of scientific societies, and serves on the Society for Neuroscience program committee. She has an ongoing commitment to research and to undergraduate and graduate education.

Vice Chair
David Arthur Shirley, Chemical Physics. David Shirley has served as a Professor of Chemistry at the University of California, Berkeley, and as Associate Director and Director of the Lawrence Berkeley National Laboratory. He served as Senior Vice President for Research and Dean of the Graduate School and Professor of Chemistry and Physics at Penn State University. He is currently Director Emeritus, LBNL, and Professor Emeritus, UC Berkeley. Dr. Shirley's research has spanned various fields in chemical and nuclear physics. He led the effort to build the Advanced Light Source at LBNL. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences, and a Fellow of the American Physical Society. He holds an Sc.D. (h.c.) University of Maine, and Dr. ret. nat. (h.c.) Free University, Berlin. He has served on several committees for the US government, UNESCO, and the National Academy of Sciences.

Andreas Acrivos, Fluid Dynamics. Professor Acrivos is the Einstein Professor of Science and Technology, Emeritus, at the City College of the City University of New York. He obtained his B.S., M.S., and Ph.D. degrees in chemical engineering from Syracuse University and the University of Minnesota. For the past 40 years, Professor Acrivos has specialized in fluid mechanics and has investigated, theoretically and experimentally, a variety of fundamental problems involving the flow of viscous fluids and the associated heat and mass transfer phenomena. He is a member of the National Academy of Sciences and the National Academy of Engineering, and is a Fellow of the American Academy of Arts and Sciences, the New York Academy of Sciences, the American Physical Society, and the American Institute of Chemical Engineers. On June 13, 2002, Dr. Acrivos is due to receive the 2001 National Medal of Science from President Bush.

Roger Beachy, Plant Biology. Dr. Beachy is President of the Donald Danforth Plant Science Center located in St. Louis, Missouri. Dr. Beachy holds a Ph.D. in plant pathology from Michigan State University and has earned a B.A. in biology from Goshen College in Goshen, Indiana. He has held several ranking positions including Division Head of Plant Biology at The Scripps Research Institute, co-director of the International Laboratory for Tropical Agriculture, and Professor and Head of the Center for Plant Science and Biotechnology, Washington University Biology Department. Dr. Beachy has received several honors for his work including election to the National Academy of Science, the Wolf Prize in Agriculture, the D. Robert Hoagland Award from the American Society for Plant Physiologists, the Common Wealth Award for Science Invention from the Bank of Delaware, and the Ruth Allen Award from the American Phytopathological Society. He is noted for his work in the development of the world's first genetically altered food crop and his contributions to a number of patent applications.

Raymond Bula, Plant Physiology. Dr. Bula earned his Ph.D., M.S., and B.S. from the University of Wisconsin-Madison and is currently a Principal in AgSpace Technologies International, LLC. He served as Director of the Wisconsin Center for Space Automation and Robotics, College of Engineering, University of Wisconsin-Madison where he led the successful ASTROCULTURE space flight experiment and hardware development program for the Space Shuttle, MIR, and International Space Station. Dr. Bula is a Fellow of the American Association for the Advancement of Science, the American Society of Agronomy, the Crop Science Society of America, the Honorary Society of Phi Kappa Phi, and is listed in American Men of Science and Who's Who in America. He is author or co-author of over 120 technical publications dealing with environmental and stress physiology of plants.

Noel Jones, Structural Biology. Noel D. Jones is retired as Research Advisor (Scientific Director) and Group Leader of Macromolecular Structure Research at Eli Lilly and Company, where he spent twenty-seven years. Subsequently he was for three years Vice President of Drug Design at Molecular Structure Corporation. He has extensive experience in macromolecular crystallography research, drug design and research management. His special expertise is in the development of automated instrumentation for protein crystallization and in the development of synchrotron beam lines for diffraction studies. Noel Jones has frequently served on NIH, NASA, and DOE review panels for evaluation of research programs. He served on the NRC Task Group for Evaluation of NASA's Biotechnology Facility for the International Space Station, 1999-2000 and the NRC Task Group for Research on the International Space Station (2001-2002)

Harold Metcalf, Atomic Physics. Dr. Metcalf was awarded a B.S. in Physics from MIT and his Ph.D. in Physics from Brown University. He has served as Visiting Professor at many academic institutions including the University of Innsbruck, RU Utrecht, Netherlands, and Ecole Normale Superieure, Paris, France; he is currently a Distinguished Teaching Professor at S.U.N.Y. Stony Brook. Dr. Metcalf is a life Member and Fellow of the American Physical Society and a member of A.P.S., O.S.A., A.A.P.T., and L.I.P.T.A. He is a Fellow of the Optical Society of America, a recipient of the Chancellor's Award for Excellence in Teaching, a Humboldt Prize Fellow, 1997-2002 at the Universities at Konstanz and Bonn, and Debye Hoogleraar, 2003 (University of Utrecht). His research interests include precision spectroscopy of simple atoms and molecules, quantum beats and atomic coherence, Zeeman spectroscopy, Stark spectroscopy of Rydberg atoms, and deceleration and cooling of atoms with laser light; he has published over 120 refereed papers and three books.

Patricia Morris, Materials Science. Patricia Morris is the Technology Manager of DuPont Chemical Sensors, leading the development of chemical sensors for environmental applications. She earned her B.S. in ceramic Engineering, Cum Laude, from Ohio State University and holds a Ph.D. in Ceramics in the Dept. of Materials Science and Engineering, with a Solid State Physics Minor, from MIT. Dr. Morris is the Vice President of the American Association for Crystal

Growth and a member on the Executive Committee of the American Association for Crystal Growth. She has served on the NSF Workshop on "Fundamental Research Needs in Ceramics" and as Associate Editor, J. Crystal Growth. Approximately 70 articles have been published on a variety of topics, ranging from thin film and bulk growth of oxides to the superconducting, nonlinear optical, photochemical and chemical sensing properties of materials.

Elaine Oran, Combustion Science. Dr. Elaine Oran is the Senior Scientist for Reactive Flow Physics at the Naval Research Laboratory. She received an A.B. degree in Physics and Chemistry from Bryn Mawr College, an M.Ph. from the Dept. Of Physics at Yale University, and a Ph.D. in Engineering and Applied Sciences from Yale. Dr. Oran is a Fellow of the American Institute of Aeronautics and Astronautics, and a Fellow of the American Physical Society; her honors include Zeldovich Gold Medal of the Combustion Institute, Honorary Professor of the University of Wales, and the Dryden Distinguished Lectureship of the AIAA. She is currently Associate Editor of the Journal of Computational Physics, Managing Editor of *Shock Waves* and has published over three hundred technical papers, written many review articles, given almost two hundred invited lectures, and coauthored the book Numerical Simulation of Reactive Flow (2nd edition Cambridge 2001).

Mary Jane Osborn, Microbial Biology. Dr. Osborn currently serves as Professor and Head of the Microbiology Department at The University of Connecticut Health Center School of Medicine. She received her B.A. in Physiology from the University of California, Berkeley and her Ph.D. in Biochemistry from the University of Washington. She has served as Assistant and Associate Professor, Albert Einstein College of Medicine, New York. Dr. Osborn is a member of the American Society of Biochemistry and Molecular Biology, the American Society of Microbiology, and the American Association for the Advancement of Science. Her honors include membership in the National Academy of Sciences and American Academy of Arts and Sciences, Chancellor's Distinguished Lectureship, University of California, Berkeley, Board of Governors, American Academy of Microbiology, and Advisory Committee, Princeton University Department of Molecular Biology. Dr. Osborn was a member of the NRC Panel on Biomedical and Biobehavioral Research Personnel Needs (1992-94), a member of the Space Studies Board (1994-2000), and Chair of the Committee on Space Biology and Medicine (1994-2000), and she is currently a member of the NAS Report Review Committee and Chair of the NRC Committee on Indicators for Waterborne Pathogens. Dr. Osborn has authored or co-authored over 80 scientific publications.

James A. Pawelczyk, Physiology. Dr. Pawelczyk is an Assistant Professor in the Department of Kinesiology and the Noll Physiological Research Center at the Pennsylvania State University, University Park, PA. He earned BA degrees in Biology and Psychology from the University of Rochester, NY; a MS in Physiology from Penn State University; a PhD in Biology from the University of North Texas, Denton, TX; and completed postdoctoral training in autonomic neurophysiology at the University of Texas Southwestern Medical Center, Dallas, TX. He served as a primary Payload Specialist on the STS-90 Neurolab mission in April and May of 1998. This 16-day mission was the final NASA Spacelab mission and was dedicated to life sciences (neuroscience) research. He is a member of the American College of Sports Medicine, American Heart Association, American Physiological Society, and Society for Neuroscience. His honors include a Doctorate in Public Service from the University of North Texas Health Science Center at Fort Worth, TX, the NASA Spaceflight Medal, and the Outstanding Faculty

Award from the Golden Key National Honor Society. He is an author on more than 100 books, articles and professional presentations.

Frederick Pohland, Environmental Engineering. Dr. Frederick G. Pohland is Professor and Edward R. Weidlein Chair of Environmental Engineering, Director of the Dominion Center for Environment and Energy, and Co-Director of the Groundwater Remediation Technologies Analysis Center at the University of Pittsburgh. He received his B.S. in Civil Engineering from Valparaiso University and his M.S. and Ph.D. in Environmental Engineering at Purdue University. He is a Registered Professional Engineer, an Honorary Member of the Water Environment Federation (WEF), an Honorary Member of the International Water Association, a Fellow and Life Member of the American Society of Civil Engineers (ASCE), a Diplomate in the American Academy of Environmental Engineers (AAEE), and a member of the National Academy of Engineering. His honors include the WEF Harrison Prescott Eddy Medal, the AAEE Gordon Maskew Fair Award, and the ASCE Simon Freeze Memorial Lecturer. Dr. Pohland has served as consultant and advisor to industry and government, and has over 150 technical and scientific publications.

Richard Roberts, Biotechnology-Genomics. Dr. Roberts is a Research Director at New England Biolabs in Beverly, Massachusetts. He was educated in England, attending the University of Sheffield where he obtained a B.Sc. in Chemistry and a Ph.D. in Organic Chemistry. He is a Fellow of the Royal Society and has received many distinguished awards including the Medicus Magnus of the Polish Academy of Medicine, the Golden Plate Award, Convocation Award, Sheffield University and has been the Albert Einstein Memorial Lecturer, Princeton. He is a shared award recipient of the 1993 Nobel Prize in Physiology or Medicine for the discovery of split genes. Dr. Roberts serves as Executive Editor of Nucleic Acids Research, as Chairman of the Scientific Advisory Boards of Celera Genomics and Lynkeus Biotech, and on the Scientific Advisory Boards of PubMed Central and Orchid Biosciences. His research interests include restriction endonucleases, DNA methylases, and computational molecular biology and he has over 200 scientific publications.

Rhea Seddon, Aerospace Medicine. Rhea Seddon is a former astronaut who holds a B.A. in Physiology from the University of California, Berkeley and an M.D. degree from the University of Tennessee College of Medicine. Besides working on Space Shuttle and Spacelab systems and operations at NASA, she also served on NASA's Institutional Review Board, Aerospace Medical Advisory Committee, International Bioethics Task Force, and as the Assistant to the Director of Flight Crew Operations for Shuttle/Mir payloads. Dr. Seddon was a Mission Specialist on STS 51D (1985) and STS 40 (1991) and the Payload Commander on STS 58 (1991) for a total of 30 days in space. She retired from NASA in 1997 and is now the Assistant Chief Medical Officer at the Vanderbilt University Medical Center in Nashville, TN. She is a member of the Institute of Medicine Committee on Aerospace Medicine.

Gary Stein, Cell Biology. Gary Stein currently serves as Professor and Chairman of the Department of Cell Biology at the University of Massachusetts Medical School and, also, as the Deputy Director for Research at the University of Massachusetts Cancer Center. He earned his B.A. and M.S. in Biology at Hofstra University, New York and his Ph.D. in Biology at the University of Vermont. Dr. Stein serves on the Editorial Board of over 20 science publications and is a member of the National Cancer Institute Basic and Pre-Clinical Review Panel, on the Advisory Committee of St. Jude Children's Research Hospital, and on the Council of the American Society for Bone & Mineral Research. His honors include the Brown University Steroid Hormone Research Award, Elected member: Pakistan Academy of Sciences, and was appointed the Gerald L. Haidak, M.D. and Zelda S. Haidak Distinguished Professor and Chair of Cell Biology. Dr. Stein is credited as co-owner of three patents and has published hundreds of technical documents. Dr. Stein chaired the National Research Council's Panel that evaluated NASA's Biotechnology Research on the International Space Station (2000).

Fred Turek, Sleep and Circadian Biology. Dr. Turek is a Professor in the Department of Neurobiology & Physiology at Northwestern University and a Professor in the Departments of Neurology and Psychiatry & Human Behavior at Northwestern University Medical School. He earned his B.S. in Biology from Michigan State, his Ph.D. in Biological Rhythms from Stanford University in CA, and completed his postdoctoral Fellowship in Biological Rhythms at the University of Texas. He currently serves as a member of the Center for Reproductive Sciences, the Lurie Cancer Center, and the Buhler Center on Aging; as Director of the Center for Sleep and Circadian Biology; and as an affiliate of the Transportation Center. His selected honors include the John Guggenheim Memorial Fellowship, an NIH Research Career Development Award, two International Fogarty Fellowships, Endowed Chair: Charles E. and Emma H. Morrison Professor of Biology, and Distinguished Investigator Award from the National Alliance for Research on Schizophrenia and Depression. He is credited with 251 scientific publications.

Raymond Viskanta, Mechanical Engineering and Heat Transfer. Raymond Viskanta is currently W.F.M. Goss Distinguished Professor of Engineering at Purdue University, in the School of Mechanical Engineering. He earned his B.S. in Mechanical Engineering from the University of Illinois and his M.S. and Ph.D. in Mechanical Engineering from Purdue University. Professor Viskanta has broad knowledge of physical sciences, transport phenomena, mathematical modeling of thermal and combustion systems, and of experimental techniques. During the last 10 years he has served as a member of the U.S. Department of Energy and U.S. Nuclear Regulatory Commission constituted peer review panels. He was a member of the Space Studies Board of the NRC and served as Chairman of the Committee on Microgravity Research. Dr. Viskanta is a member of the National Academy of Engineering and is a Fellow of the American Institute of Aeronautics and Astronautics and the American Society of Mechanical Engineers. His honors include the ASME/AIChE Max Jakob Memorial Award, an honorary doctor of engineering degree (Doctor Honoris Causa) from the Technical University of Munich, and Foreign Member - Academy of Engineering Sciences of the Russian Federation. Professor Viskanta has authored or co-authored over 500 refereed papers, has prepared over 50 invited review articles, and has directed the doctoral research of over 100 students and post-doctoral researchers.

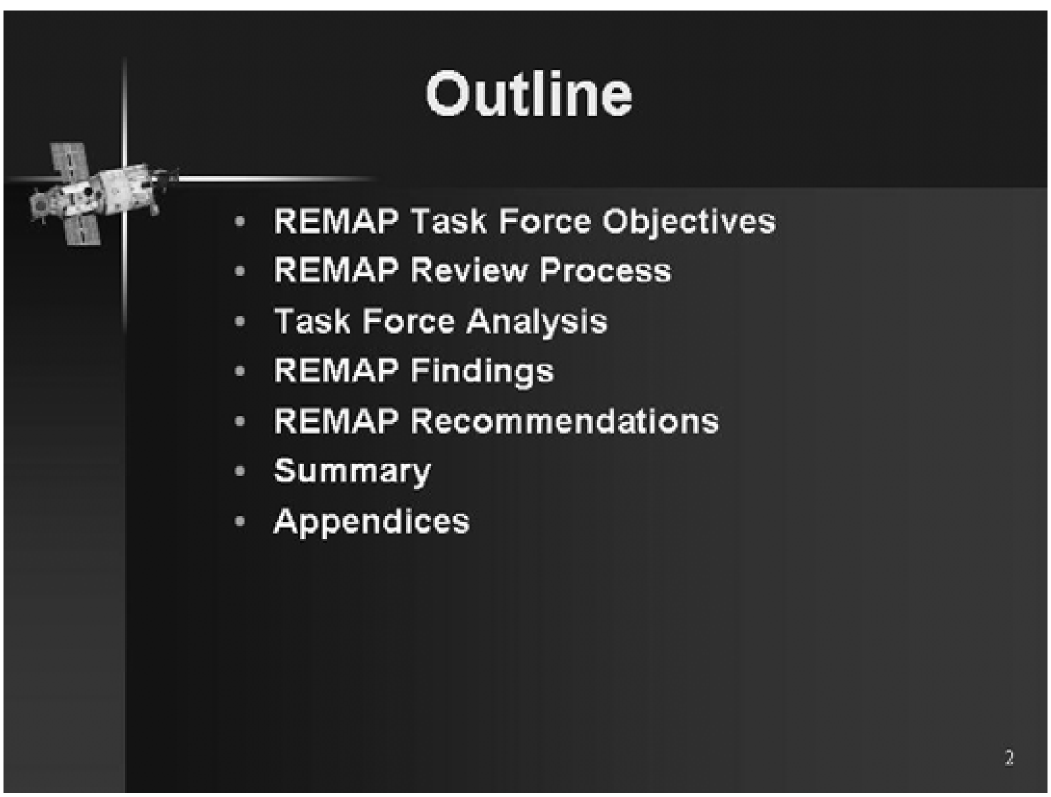
George Whitesides, Nanotechnology in Biomolecules. George Whitesides received an A.B. degree from Harvard University and a Ph. D. from the California Institute of Technology. He is employed as Mallinckrodt Professor of Chemistry at Harvard University. Dr. Whitesides received the National Medal of Science in 1999. He is a member of the American Academy of Arts and Sciences, the National Academy of Sciences, and the American Philosophical Society. He serves the National Research Council as a member of the Committee on Science and

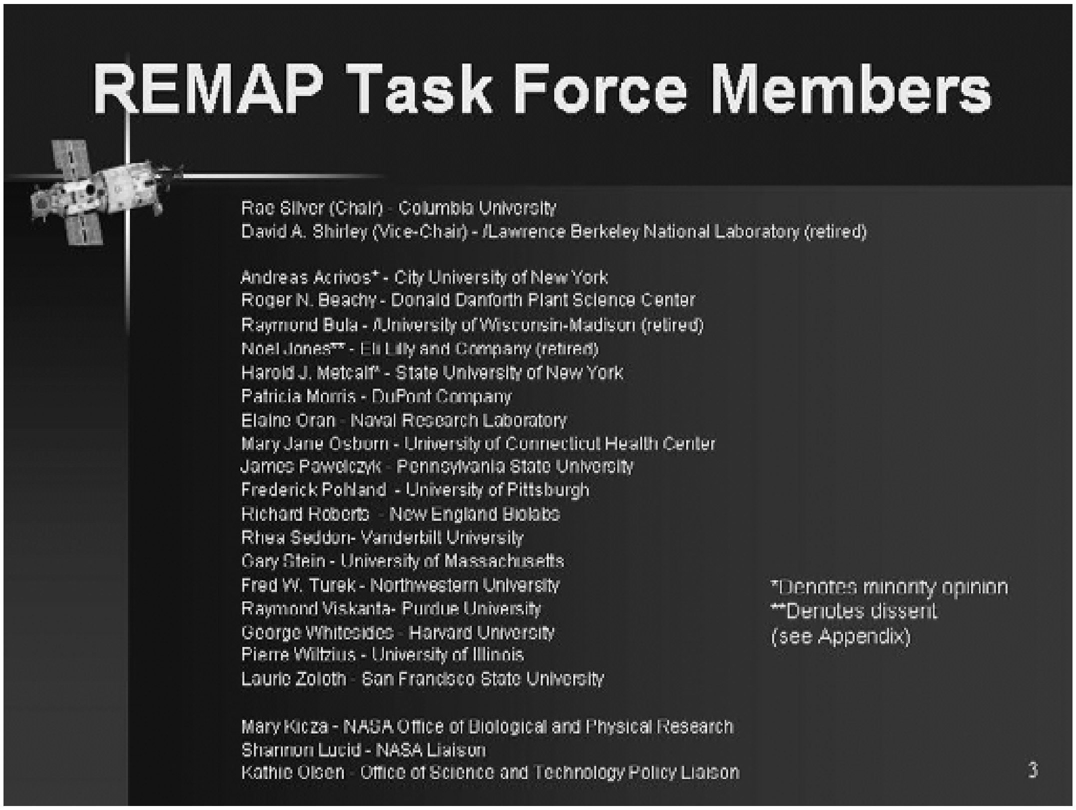
Technology for Counterterrorism, and the Defense Science Board of the Department of Defense. Present research interests include materials science, biophysics, complexity, surface science, microfluidics, self-assembly, micro- and nanotechnology, and cell-surface biochemistry.

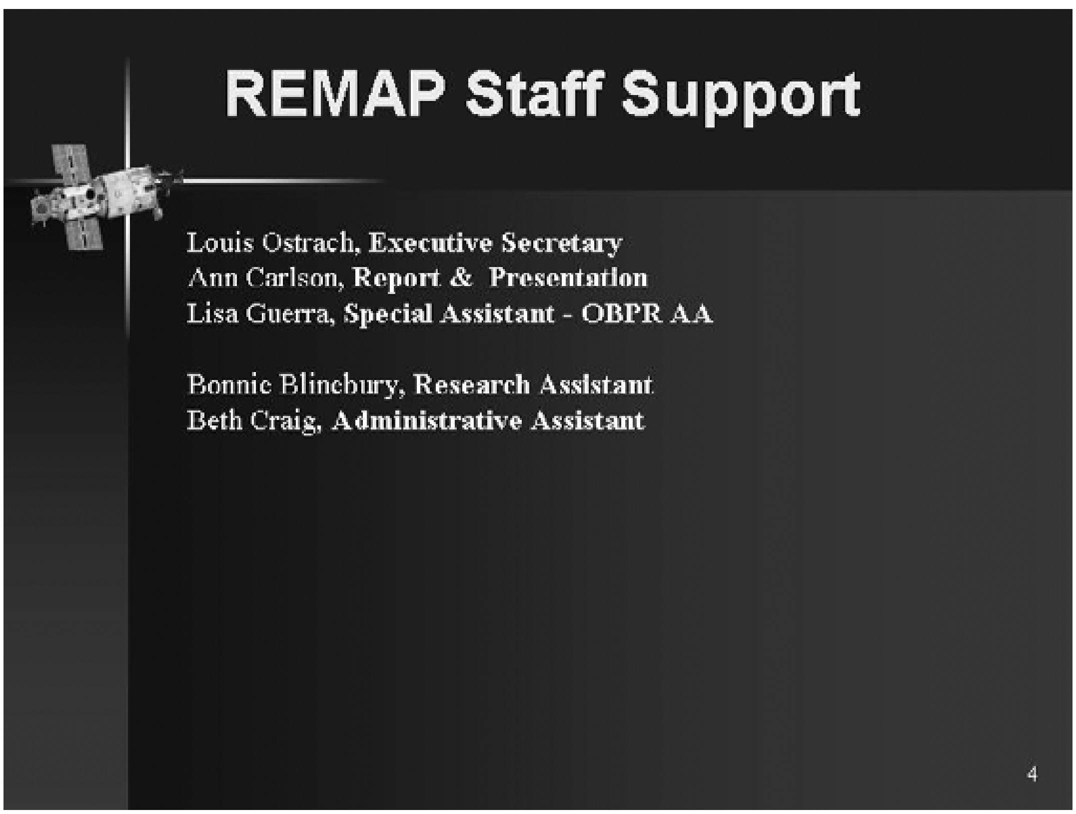
Pierre Wiltzius, Physics, Materials Sciences, and Engineering. Pierre Wiltzius received his Ph.D. in physics from the Swiss Federal Institute of Technology (ETHZ), Zurich, Switzerland. He currently serves as Director of the Beckman Institute for Advanced Science and Technology at the University of Illinois; a professor in both the Departments of Materials Science and Engineering, and Physics; and a full-time Beckman Institute faculty member in the Nanoelectronics and Biophotonics Group. Dr. Wiltzius has received many honors that include Fellow of the American Physical Society; Fellow of the American Association for the Advancement of Science; Senior Member of the IEEE; and R&D100 Innovation Award from R&D Magazine, Distinguished Member of Technical Staff at Bell Laboratories/Lucent Technologies. His fields of professional interest are soft-condensed matter, colloidal self-assembly, photonic crystals and microphotonics and he has published six scientific documents within the past 2 years.

Laurie Zoloth, Bioethics. Laurie Zoloth is Professor of Ethics and Director of the Program in Jewish Studies at San Francisco State University. In 2000, she was President of the American Society of Bioethics and Humanities. She is a member of the NASA National Advisory Council, the NASA Planetary Protection Advisory Committee, the NIH DSMB for Aids Research, the NIH ELSI Planning and Assessment Committee, the Executive Committee of the International Society for Stem Cell Research, and is the Chair of the Howard Hughes Medical Institute's Bioethics Advisory Board. Professor Zoloth received her BA in Women's Studies and History from the University of California at Berkeley, her BSN from the University of the State of New York, her MA in English from San Francisco State University, her MA in Jewish Studies and her Ph.D. in Social Ethics at the Graduate Theological Union in Berkeley. She has published extensively in the areas of justice and resource allocation, ethics, family, feminist theory, religion and science, Jewish Studies, and social policy and has authored 3 books, edited 3 others, and authored chapters in 27 books. She is the bioethics consultant to NASA Ames Research Center, and the NASA Interagency National Animal Care and Use Committees and is currently the emerging issues in medical and research genetics.

APPENDIX C: Briefing to NASA Advisory Council by ReMAP




REMAP Task Force Members
Rae Silver (Chair) - Columbia University
David A. Shirley (Vice-Chair) - /Lawrence Berkeley National Laboratory (retired)
Andreas Acrivos* - City University of New York
Roger N. Beachy - Donald Danforth Plant Science Center
Raymond Bula - /University of Wisconsin-Madison (retired)
Noel Jones** - Eli Lilly and Company (retired)
Harold J. Metcalf* - State University of New York
Patricia Morris - DuPont Company
Elaine Oran - Naval Research Laboratory
Mary Jane Osborn - University of Connecticut Health Center
James Pawelczyk - Pennsylvania State University
Frederick Pohland - University of Pittsburgh
Richard Roberts - New England Biolabs
Rhea Seddon- Vanderbilt University
Gary Stein - University of Massachusetts
Fred W. Turek - Northwestern University
Raymond Viskanta- Purdue University
George Whitesides - Harvard University
Pierre Wiltzius - University of Illinois
Laurie Zoloth - San Francisco State University
Mary Kicza - NASA Office of Biological and Physical Research
Shannon Lucid - NASA Liaison
Kathie Olsen - Office of Science and Technology Policy Liaison
*Denotes minority opinion
**Denotes dissent
(see Appendix)
3


REMAP Staff Support
Louis Ostrach, Executive Secretary
Ann Carlson, Report & Presentation
Lisa Guerra, Special Assistant - OBPR AA
Bonnie Blinebury, Research Assistant
Beth Craig, Administrative Assistant
4

Schedule of Activities

Date	Location	Activity
April 2-3	NASA HQ	Introductions, fact finding
April 3-22		Homework
April 19	New York, NY	Sub-committee meeting with International Partners
April 23-24	NASA HQ	Prioritization of science research within OBPR
April 25-May 15		Homework
May 16-17	NASA HQ	Review or Implementation options, report preparation
May 18-May 31		Writing from home
June 5	NASA HQ	Draft REMAP report not ready: Requested extension granted
July 10	NASA HQ	Report delivered to NASA Advisory Council

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Background

- President's FY2003 Budget Request:
  - NASA is to engage the scientific community and establish high-priority science objectives for OBPR
  - Focus on improving scientific productivity
- ISS Management and Cost Evaluation (IMCE) Task Force Recommendation:
  - OBPR to establish scientific research priorities and,
  - Develop executable research program consistent with those priorities

6

Overall REMAP Objectives

- Assess research priorities and productivity for the entire scientific, technological, and commercial portfolio of NASA's Biological and Physical Research Enterprise
- Provide recommendations on how to achieve the greatest progress in high-priority research

7

REMAP Task Force Review Process

- **Structured briefings**
  - OBPR research programs, priorities and criteria
  - OBPR implementation analysis
  - Previous reports to NASA on OBPR research
- **Independent Reports**
  - International Partners
  - NRC Committee for Microgravity Research
- **Executive Sessions & Task Force Discussions**
  - Establish REMAP priorities of OBPR research portfolio

8

Input (non-NASA): Previous Reviews - Bioastronautics and Fundamental Biology Divisions

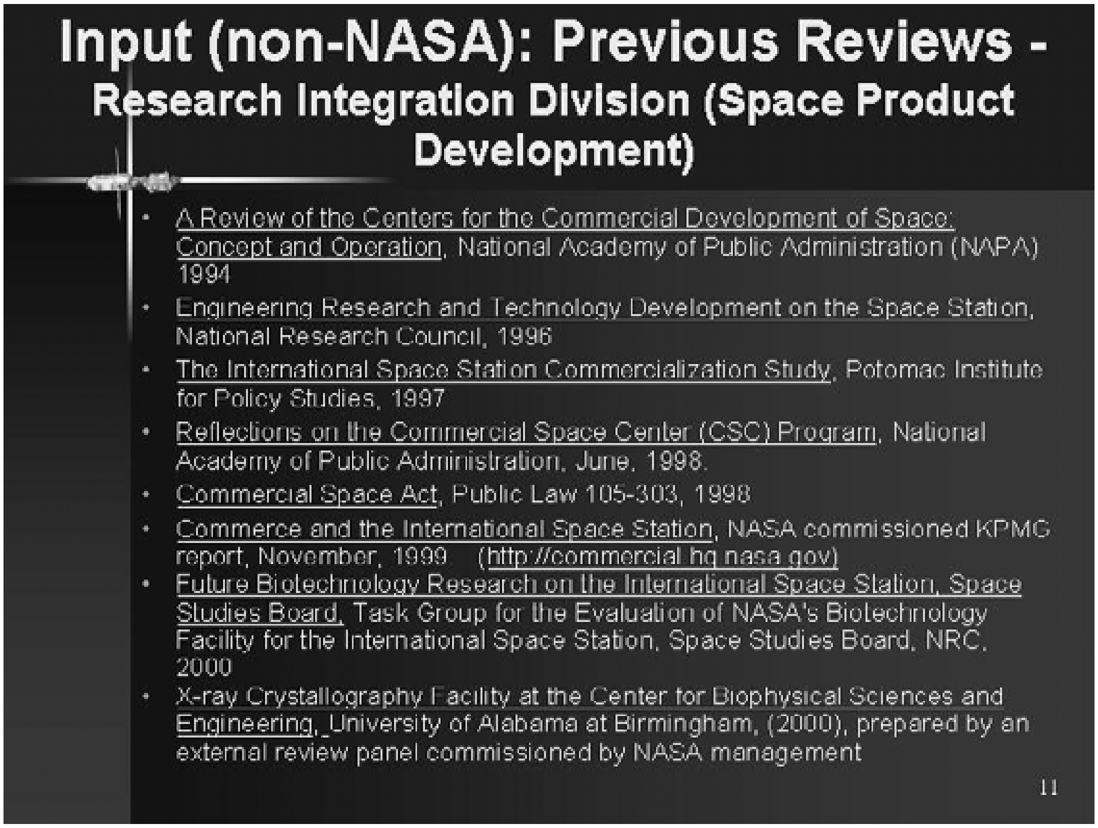
- A Strategy for Space Biology and Medical Sciences for the 1980s and 1990s, Committee on Space Biology and Medicine, Space Science Board, NRC,1987
- Assessment of Programs in Space Biology and Medicine, Committee on Space Biology and Medicine, Space Studies Board, NRC, 1991
- Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies, Task Group on Biological Effects of Radiation, Space Studies Board, NRC, 1996
- Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, Committee on Advanced Technology for Human Support in Space, NRC, 1997.
- A Strategy for Research in Space Biology and Medicine in the New Century, Committee on Space Biology and Medicine, Space Studies Board, NRC, 1998
- Future Biotechnology Research on the International Space Station, Space Studies Board, Task Group for the Evaluation of NASA's Biotechnology Facility for the International Space Station, Space Studies Board, NRC, 2000
- Review of NASA's Biomedical Research Program, Committee on Space Biology and Medicine, Space Studies Board, NRC, 2000
- Safe Passage: Astronaut Care for Exploration Missions, Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit, Board on Health Sciences Policy, IOM, 2001.

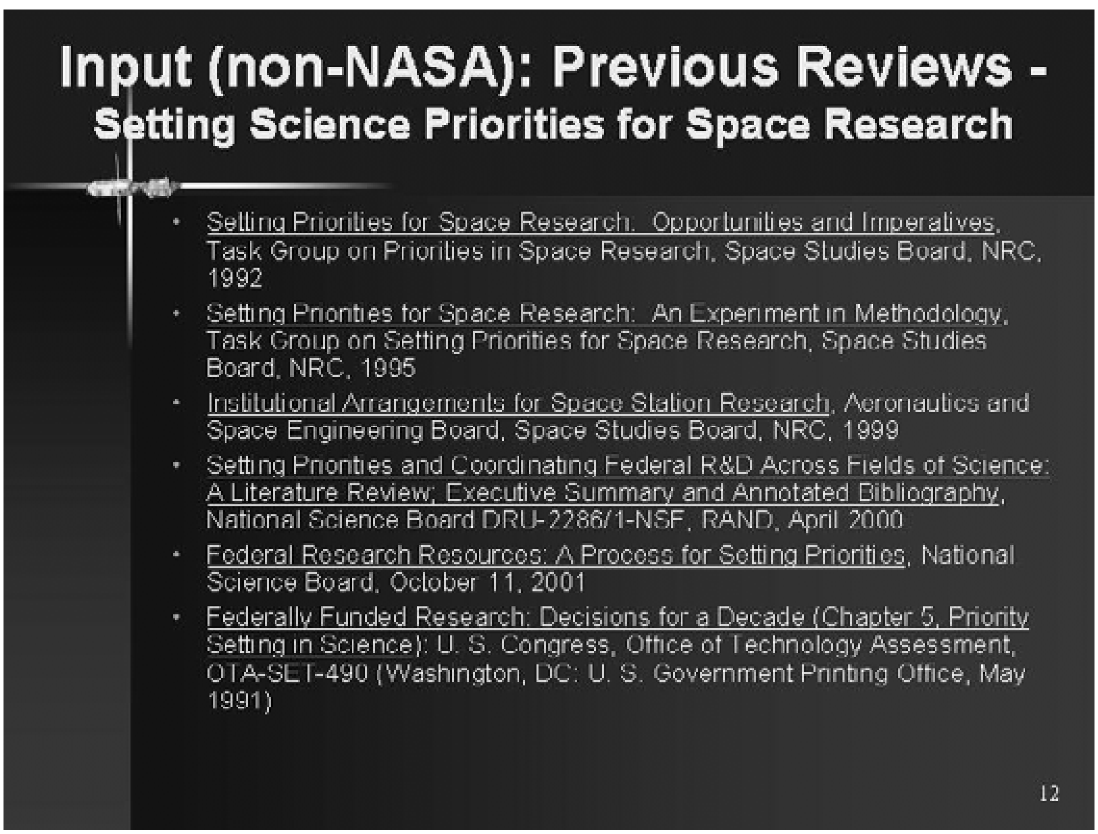
9

Input (non-NASA): Previous Reviews - Physical Sciences Division

- Toward a Microgravity Research Strategy, Committee on Microgravity Research, Space Studies Board, NRC, 1988
- Space Science in the Twenty-First Century: Imperatives for the Decades 1995 to 2015—Fundamental Physics and Chemistry, Task Group on Fundamental Physics and Chemistry, Space Studies Board, NRC,1988
- Microgravity Research Opportunities for the 1990's, Committee on Microgravity Research, Space Studies Board, NRC, 1995
- Future Materials Science Research on the International Space Station National Materials Advisory Board, NRC, 1997
- Microgravity Research in Support of Technology for the Human Exploration and Development of Space and Planetary Bodies, Committee on Microgravity Research, Space Studies Board, NRC, 2000
- Future Biotechnology Research on the International Space Station, Task Group for the Evaluation of NASA's Biotechnology Facility for the International Space Station, NRC, 2000
- The Mission of Microgravity and Physical Sciences Research at NASA, Committee on Microgravity Research, Space Studies Board, NRC, 2000
- Readiness Issues Related to Research in the Biological and Physical Sciences on the International Space Station, Task Group on Research on the International Space Station, Space Studies Board, NRC, 2001
- ISS/IMCE Task Force Report, NASA, 2001

10


Input (non-NASA): Previous Reviews - Research Integration Division (Space Product Development)
• A Review of the Centers for the Commercial Development of Space: Concept and Operation, National Academy of Public Administration (NAPA) 1994
• Engineering Research and Technology Development on the Space Station, National Research Council, 1996
• The International Space Station Commercialization Study, Potomac Institute for Policy Studies, 1997
• Reflections on the Commercial Space Center (CSC) Program, National Academy of Public Administration, June, 1998.
• Commercial Space Act, Public Law 105-303, 1998
• Commerce and the International Space Station, NASA commissioned KPMG report, November, 1999 (http://commercial.hq.nasa.gov)
• Future Biotechnology Research on the International Space Station, Space Studies Board, Task Group for the Evaluation of NASA's Biotechnology Facility for the International Space Station, Space Studies Board, NRC, 2000
• X-ray Crystallography Facility at the Center for Biophysical Sciences and Engineering, University of Alabama at Birmingham, (2000), prepared by an external review panel commissioned by NASA management
11


Input (non-NASA): Previous Reviews - Setting Science Priorities for Space Research
• Setting Priorities for Space Research. Opportunities and Imperatives, Task Group on Priorities in Space Research, Space Studies Board, NRC, 1992
• Setting Priorities for Space Research: An Experiment in Methodology, Task Group on Setting Priorities for Space Research, Space Studies Board, NRC, 1995
• Institutional Arrangements for Space Station Research, Aeronautics and Space Engineering Board, Space Studies Board, NRC, 1999
• Setting Priorities and Coordinating Federal R&D Across Fields of Science: A Literature Review; Executive Summary and Annotated Bibliography, National Science Board DRU-2286/1-NSF, RAND, April 2000
• Federal Research Resources: A Process for Setting Priorities, National Science Board, October 11, 2001
• Federally Funded Research: Decisions for a Decade (Chapter 5, Priority Setting in Science): U. S. Congress, Office of Technology Assessment, OTA-SET-490 (Washington, DC: U. S. Government Printing Office, May 1991)
12

Framework for Review: Process

- REMAP performed its prioritization analysis without regard to facility constraints.
- REMAP was informed of the extent to which NASA can address the priorities, given the current and planned ISS budget and capabilities.
- This information did not affect the priorities identified.

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Framework for Review: Identifying Best Research

- REMAP was charged to identify the best science that could be done by OBPR.
- The diversity of expertise and limited meeting times constrained REMAP to focus on the existing OBPR research program.

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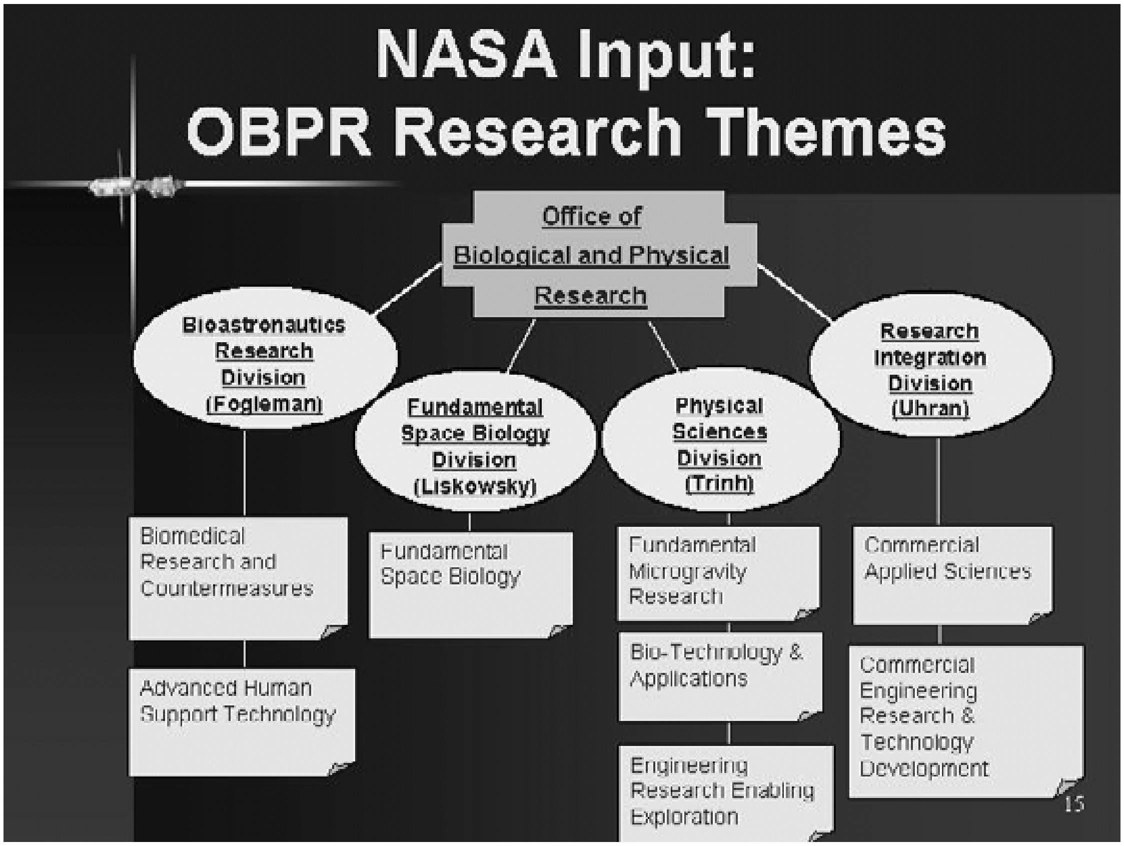
NASA Input:
OBPR Research Themes
Office of
Biological and Physical
Research
Bioastronautics
Research
Division
(Fogleman)
Fundamental
Space Biology
Division
(Liskowsky)
Physical
Sciences
Division
(Trinh)
Research
Integration
Division
(Uhran)
Biomedical
Research and
Countermeasures
Advanced Human
Support Technology
Fundamental
Space Biology
Fundamental
Microgravity
Research
Bio-Technology &
Applications
Engineering
Research Enabling
Exploration
Commercial
Applied Sciences
Commercial
Engineering
Research &
Technology
Development
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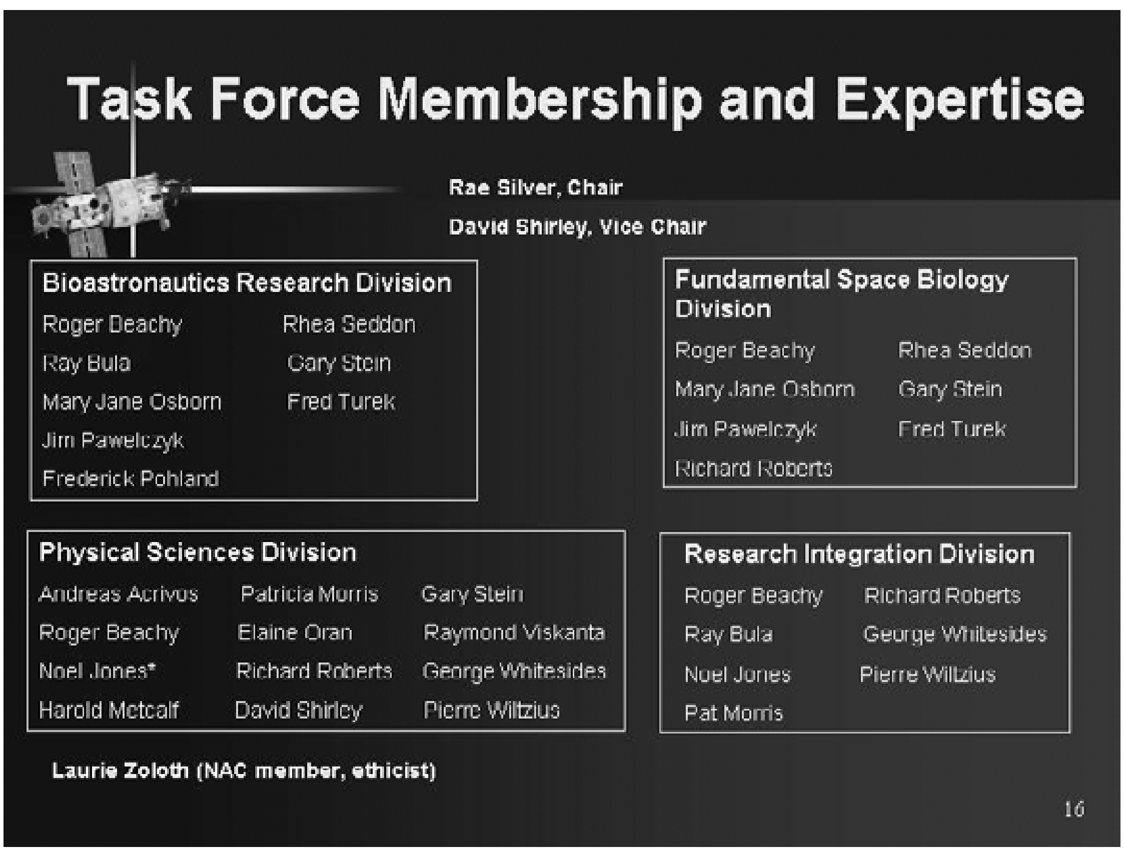
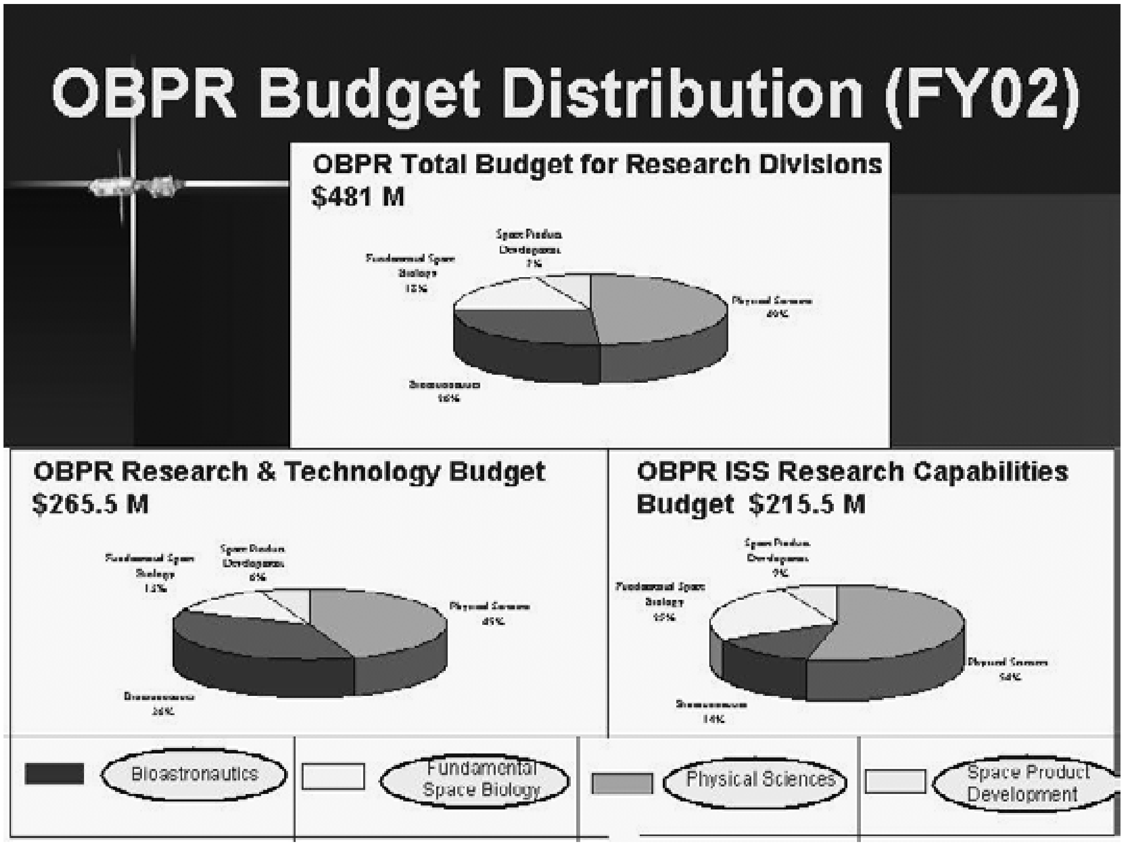
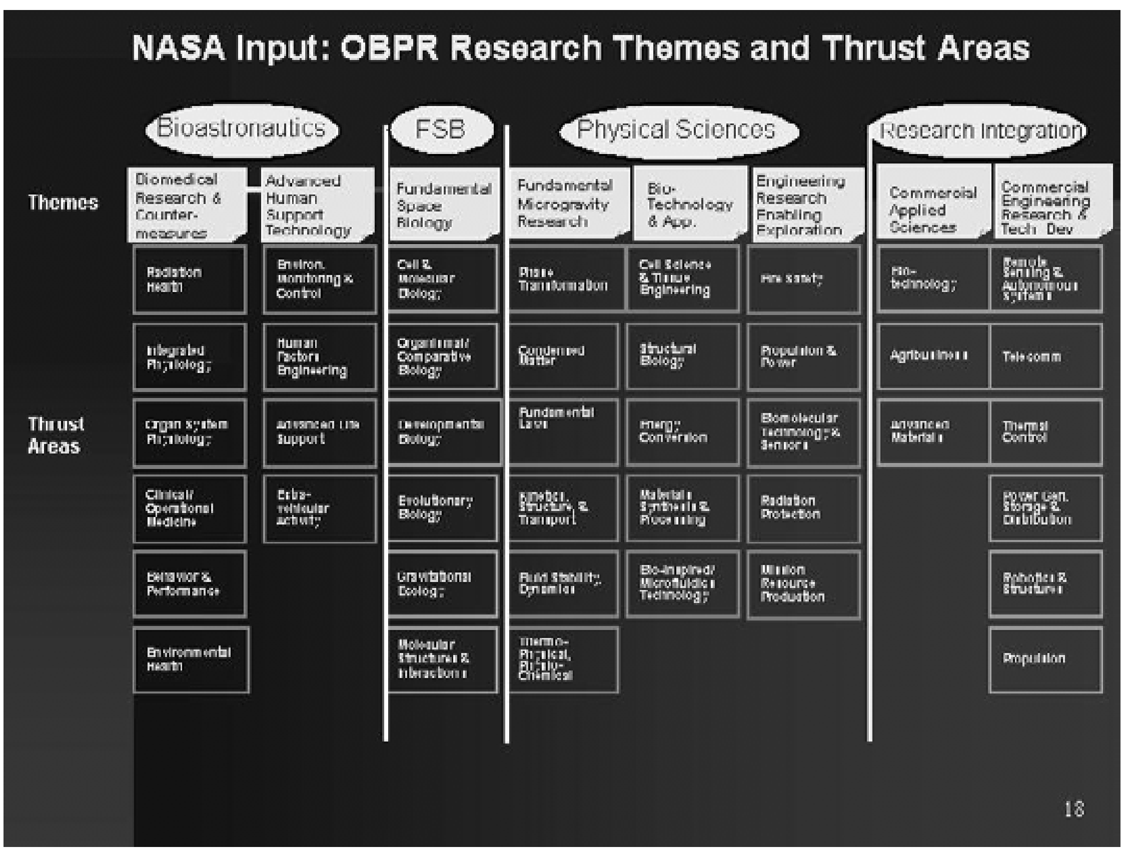

Task Force Membership and Expertise
Rae Silver, Chair
David Shirley, Vice Chair
Bioastronautics Research Division
Roger Beachy
Rhea Seddon
Ray Bula
Gary Stein
Mary Jane Osborn
Fred Turek
Jim Pawelczyk
Frederick Pohland
Fundamental Space Biology Division
Roger Beachy
Rhea Seddon
Mary Jane Osborn
Gary Stein
Jim Pawelczyk
Fred Turek
Richard Roberts
Physical Sciences Division
Andreas Acrivos
Patricia Morris
Gary Stein
Roger Beachy
Elaine Oran
Raymond Viskanta
Noel Jones*
Richard Roberts
George Whitesides
Harold Metcalf
David Shirley
Pierre Wiltzius
Research Integration Division
Roger Beachy
Richard Roberts
Ray Bula
George Whitesides
Noel Jones
Pierre Wiltzius
Pat Morris
Laurie Zoloth (NAC member, ethicist)
16


OBPR Budget Distribution (FY02)
OBPR Total Budget for Research Divisions $481 M
OBPR Research & Technology Budget $265.5 M
OBPR ISS Research Capabilities Budget $215.5 M
Bioastronautics
Fundamental Space Biology
Physical Sciences
Space Product Development


NASA Input: OBPR Research Themes and Thrust Areas
Bioastronautics
FSB
Physical Sciences
Research Integration
Themes
Thrust Areas
Biomedical Research & Counter-measures
Advanced Human Support Technology
Fundamental Space Biology
Fundamental Microgravity Research
Bio-Technology & App.
Engineering Research Enabling Exploration
Commercial Applied Sciences
Commercial Engineering Research & Tech Dev
Radiation Health
Integrated Physiology
Organ System Physiology
Clinical/ Operational Medicine
Behavior & Performance
Environmental Health
Environ. Monitoring & Control
Human Factors Engineering
Advanced Life Support
Extra-vehicular activity
Cell & Molecular Biology
Organismal/ Comparative Biology
Developmental Biology
Evolutionary Biology
Gravitational Ecology
Molecular Structures & Interactions
Phase Transformation
Condensed Matter
Fundamental Laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Thermo-Physical, Physio-Chemical
Cell Science & Tissue Engineering
Structural Biology
Energy Conversion
Materials Synthesis & Processing
Bio-inspired/ Microfluidics Technology
Fire Safety
Propulsion & Power
Biomolecular Technology & Sensors
Radiation Protection
Mission Resource Production
Bio-technology
Agribusiness
Advanced Materials
Remote Sensing & Autonomous Systems
Telecomm
Thermal Control
Power Gen. Storage & Distribution
Robotics & Structures
Propulsion
18

REMAP Task Force According to 8 OBPR Research Themes

Biomedical Research & Countermeasures
- Roger Beachy
- Mary Jane Osborn
- Jim Pawelczyk
- Rhea Seddon
- Gary Stein
- Fred Turek

Advanced Human Support Technology
- Ray Bula
- Jim Pawelczyk
- Frederick Pohland
- Rhea Seddon
- Fred Turek
- Raymond Viskanta

Fundamental Space Biology
- Roger Beachy
- Mary Jane Osborn
- Jim Pawelczyk
- Richard Roberts
- Rhea Seddon
- Gary Stein
- Fred Turek

Fund. Microgravity Research
- Andreas Acrivos
- Harold Metcalf
- Patricia Morris
- Elaine Oran
- David Shirley
- George Whitesides
- Pierre Wiltzius
- Raymond Viskanta

Biotechnology and Applications
- Roger Beachy
- Noel Jones
- Elaine Oran
- Richard Roberts
- Gary Stein
- George Whitesides
- Pierre Wiltzius

Engineering Research Enabling Exploration
- Andreas Acrivos
- Elaine Oran
- Raymond Viskanta
- George Whitesides
- Pierre Wiltzius

Commercial Applied Sciences
- Roger Beachy
- Ray Bula
- Noel Jones
- Richard Roberts
- George Whitesides
- Pierre Wiltzius

Commercial Engineering Research & Tech. Development
- Ray Bula
- Pat Morris
- Richard Roberts
- George Whitesides

- Laurie Zoloth (NAC member, ethicist) participated in all teams

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Task Force Analysis of OBPR Research, Programs & Priorities

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Justification: 1st Priority Research

- The research is essential to enable future space exploration.
- The research could reveal fundamental laws of nature.
- The research is targeted toward systems with a known direct response to gravity.
- The research is hypothesis based.
- The research requires microgravity, human intervention, and long-term access to space.
- If pertaining to countermeasure development, it is mechanism based.
- There is potential for substantial increase in capability, efficiency or cost effectiveness as a result of this research.
- The project enables the development of a new generation of research scholars by training graduate and postdoctoral students.
- There is a high probability of developing technology and applications that will be useful on earth and in space.
- There is an effective research community for quality ground- and flight- based research.

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Justification: 2nd Priority Research

- The research effectively utilizes the unique capabilities of the ISS.
- The research lowers flight risks, improves training and enhances performance of astronauts and equipment.
- The research provides better understanding of critical areas in which we already have reliable theories and/or data.
- The research tests whether the system has a direct response to gravity, or requires access to microgravity to be continued.

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Justification: 3rd & 4th Priority Research

- There has been negative or unclear past experience with this type of space research so that the basic hypothesis now appears questionable.
- NASA is not the appropriate funding agency – it is not in NASA's mission.
- NASA can draw heavily or entirely on other agency's research. Others are better able to do the research.
- The requirement for space-based research in microgravity or for ISS is not evident.

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OVERALL Finding on Research Priorities for ISS

Research of highest priority fell into two broad categories:

- Enables Human Exploration of Space
- Intrinsic Scientific Merit

These two categories are consonant with the historical goals of OBPR.

- Some research emphasizes human exploration of space.
- Some research emphasizes intrinsic scientific importance and impact.
- Some research overlaps both goals.

Prioritization between these categories is a NASA programmatic decision.

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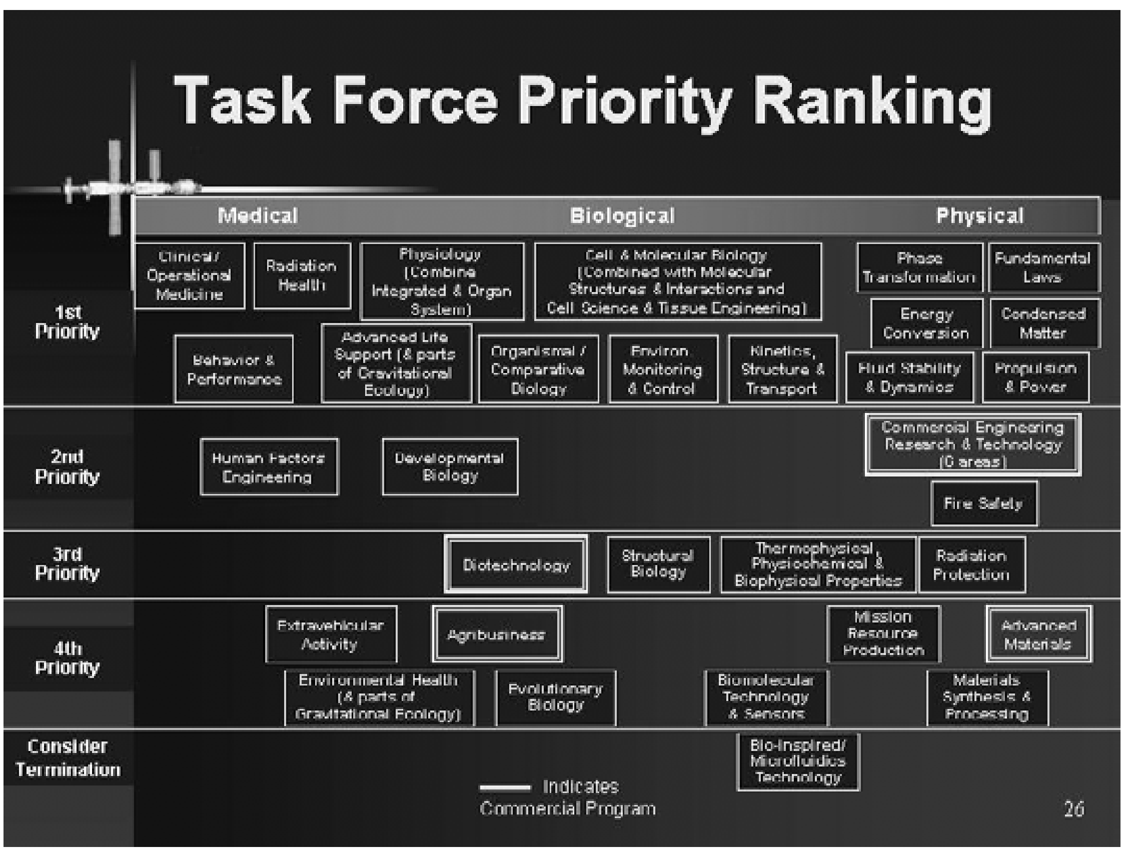
Finding: Categorization of Highest Priority Research
Enables Human Exploration of Space
Radiation Health
Behavior and Performance
Advanced Life Support
Clinical / Operational Medicine
Propulsion and Power
Integrated Physiology
Environmental Monitoring and Control
Organismal and Comparative Biology
Intrinsic Scientific Importance or Impact
Phase Transformation
Condensed Matter
Fundamental Laws
Kinetics Structure & Transport
Fluid Stability & Dynamics
Energy Conversion
Cell and Molecular Biology
This schematic does not imply strict adherence of projects to a specific category
25


Task Force Priority Ranking
Medical
Biological
Physical
1st Priority
Clinical / Operational Medicine
Radiation Health
Physiology (Combine Integrated & Organ System)
Cell & Molecular Biology (Combined with Molecular Structures & Interactions and Cell Science & Tissue Engineering)
Phase Transformation
Fundamental Laws
Energy Conversion
Condensed Matter
Behavior & Performance
Advanced Life Support (& parts of Gravitational Ecology)
Organismal / Comparative Biology
Environ Monitoring & Control
Kinetics, Structure & Transport
Fluid Stability & Dynamics
Propulsion & Power
2nd Priority
Human Factors Engineering
Developmental Biology
Commercial Engineering Research & Technology (6 areas)
Fire Safety
3rd Priority
Biotechnology
Structural Biology
Thermophysical, Physiochemical & Biophysical Properties
Radiation Protection
4th Priority
Extravehicular Activity
Agribusiness
Mission Resource Production
Advanced Materials
Environmental Health (& parts of Gravitational Ecology)
Evolutionary Biology
Biomolecular Technology & Sensors
Materials Synthesis & Processing
Consider Termination
Bio-Inspired/ Microfluidics Technology
Indicates Commercial Program
26

REMAP Findings

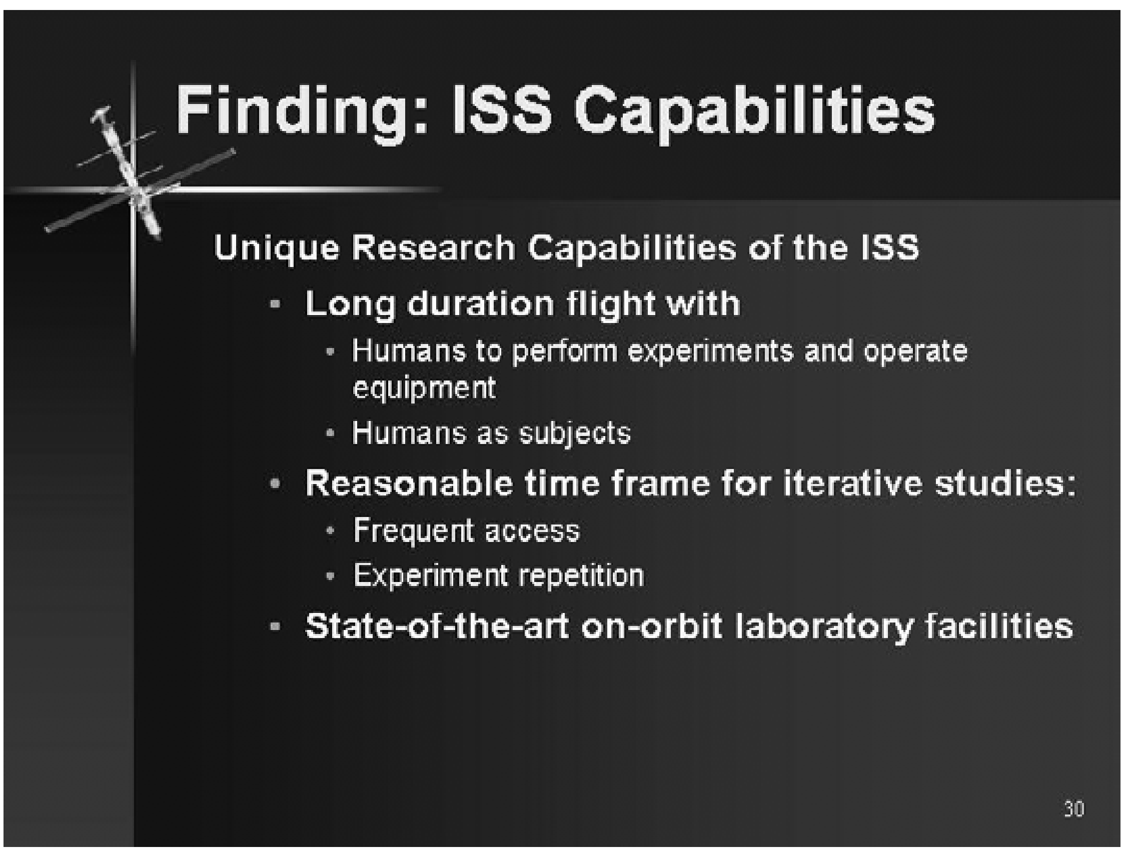
27

Finding: Historic View of Prioritization

- **Context for Development of OBPR Research Program**
  - The OBPR research programs evolved in the absence of stable budgets and predictable flight access.
  - Prioritization of research questions of OBPR has not been possible in this context.
- **Previous External Reports**
  - NASA's Space Research Program has been reviewed many times.
  - Consecutive reports have generally reached the same major conclusions.

28


Finding: OBPR Research Platforms
The OBPR research program includes elements that:
Require ISS
ISS is optimal but not necessary
Can be addressed using the Shuttle
Can be addressed using free flyers
Can be addressed in ground based research
29


Finding: ISS Capabilities
Unique Research Capabilities of the ISS
Long duration flight with
Humans to perform experiments and operate equipment
Humans as subjects
Reasonable time frame for iterative studies:
Frequent access
Experiment repetition
State-of-the-art on-orbit laboratory facilities
30

Finding: ISS Biological Research Needs a Centrifuge

- The Task Force encourages expedited development of the centrifuge with appropriate external review and guidance to insure timely deployment.
- The ISS centrifuge serves two essential research functions in the biological sciences:
  - it provides a rigorous in-flight control condition with a centrifugal field where gravity-driven forces can act, and
  - it produces a variable gravity field to identify threshold loading conditions that might facilitate biological processes.
- Engineering aspects of the centrifuge appear to be largely resolved.
- Current engineering analysis indicates that the centrifuge will not violate ISS microgravity requirements.
- If necessary, centrifuge use could be scheduled to eliminate (currently unforseen) interactions with other experiments.

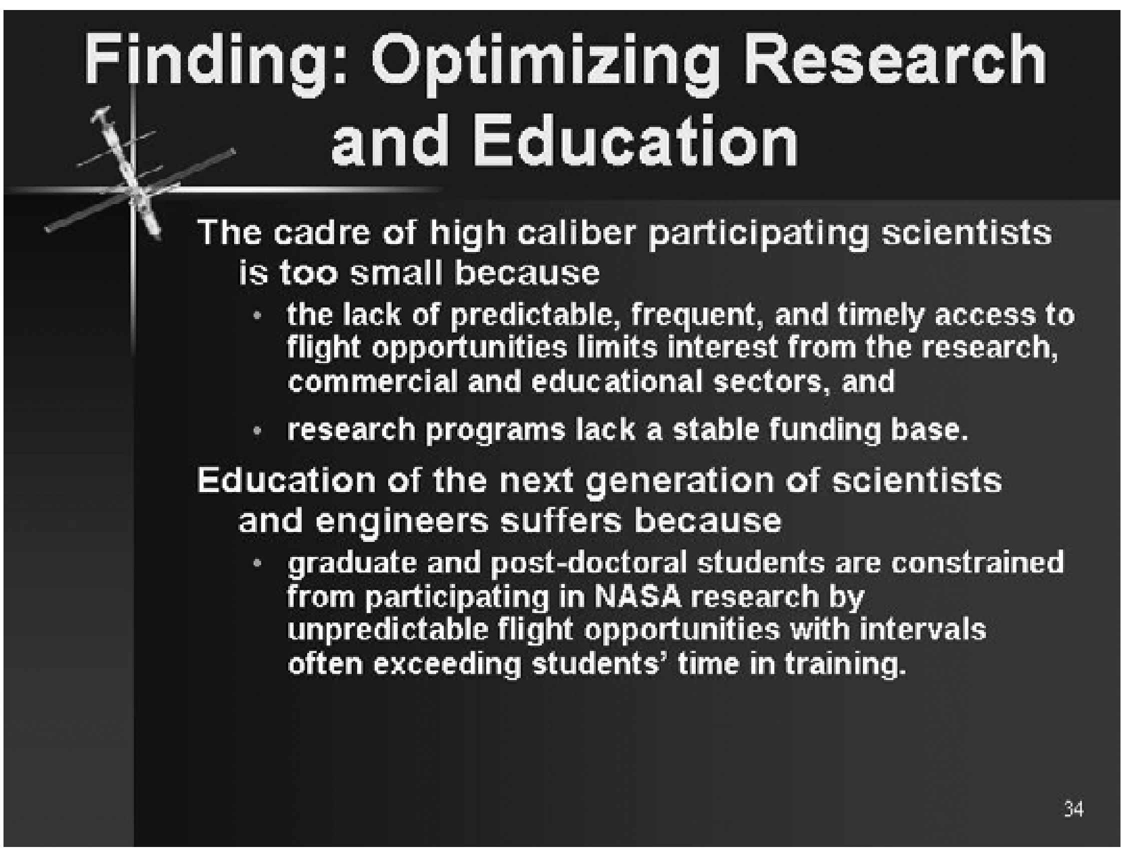
31

Finding: OBPR Organization

- OBPR organization, program structure, and solicitation mechanisms:
  - are based on research discipline,
  - lack a strategic approach,
  - are not optimal for identification and implementation of high priority/high impact research.
- Strategic approach may identify:
  - Expected outcomes
  - Roadmap to achieving goals
  - Most effective organization to achieve goals
  - Appropriate mechanics for solicitations
  - Appropriate modes for research (e.g., team approach or single investigator)
  - Need for sunset condition on research projects

32


Finding: Need for Commercial Research
• Public Law 105-330 establishes as public policy the commercial use of the ISS, and NASA's role in facilitating this use.
• The Task Force used the research merit criteria developed.
• Evaluation of the commercial programs required additional criteria appropriate for commercial activities. These include:
• private sector interest and investment,
• national economic priorities, and contributions to economic growth.
33

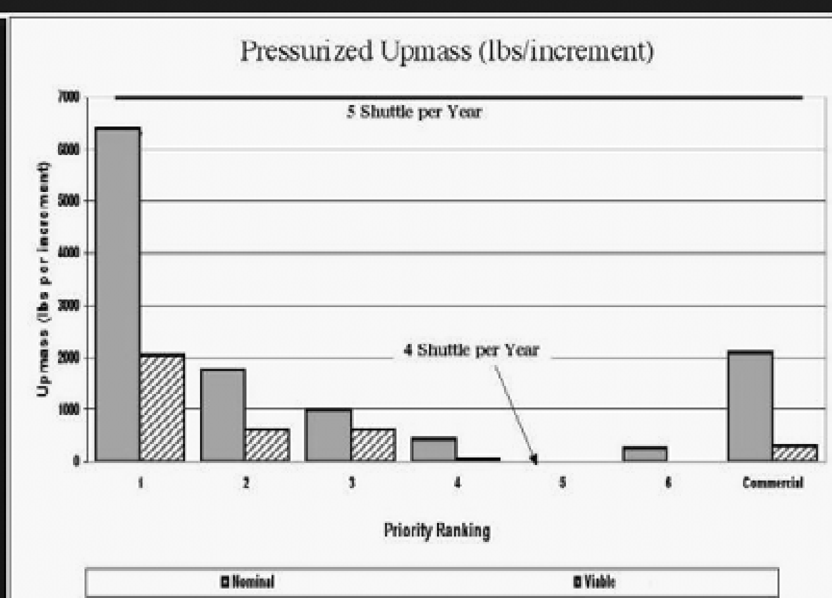

Finding: Optimizing Research and Education
The cadre of high caliber participating scientists is too small because
• the lack of predictable, frequent, and timely access to flight opportunities limits interest from the research, commercial and educational sectors, and
• research programs lack a stable funding base.
Education of the next generation of scientists and engineers suffers because
• graduate and post-doctoral students are constrained from participating in NASA research by unpredictable flight opportunities with intervals often exceeding students' time in training.
34

OBPR Finding: Preliminary Implementation Analysis of 1st and 2nd Priority Research

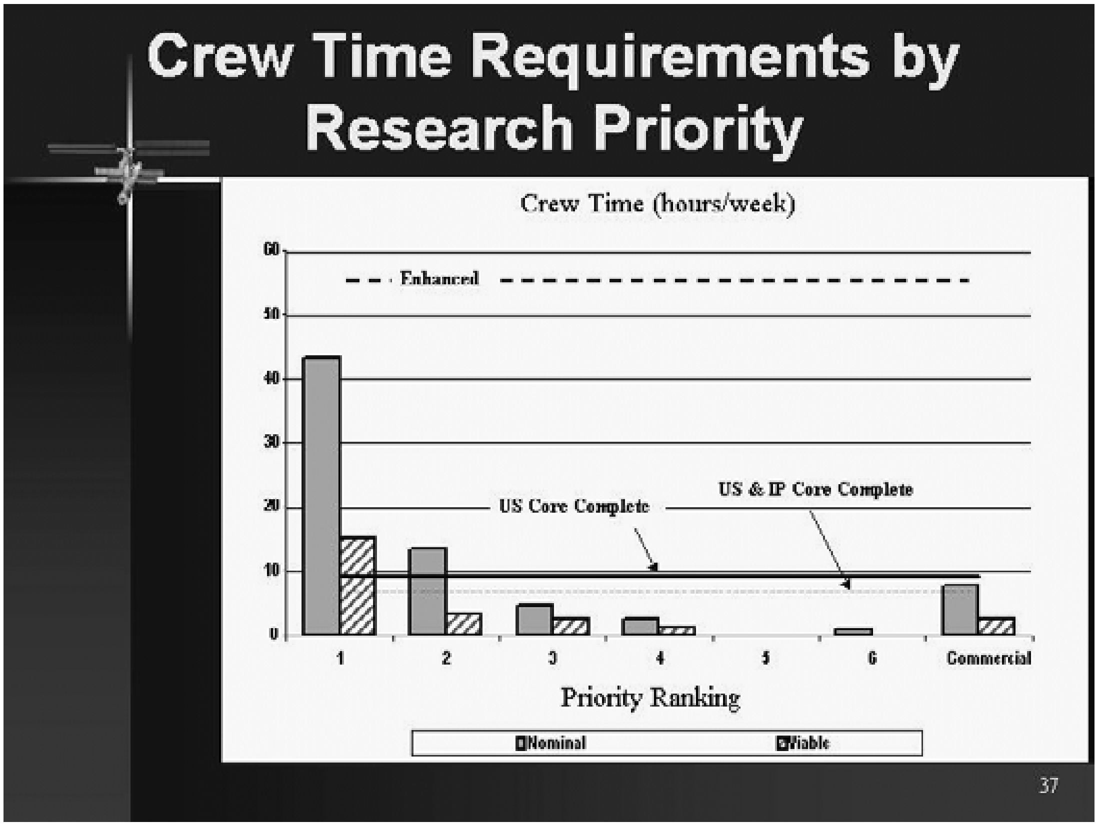
- Most of the REMAP research priority findings were established at REMAP Meeting #2.
- OBPR preliminary ISS Implementation analysis was conducted following meeting #2 and was based on these interim Task Force research priority findings.

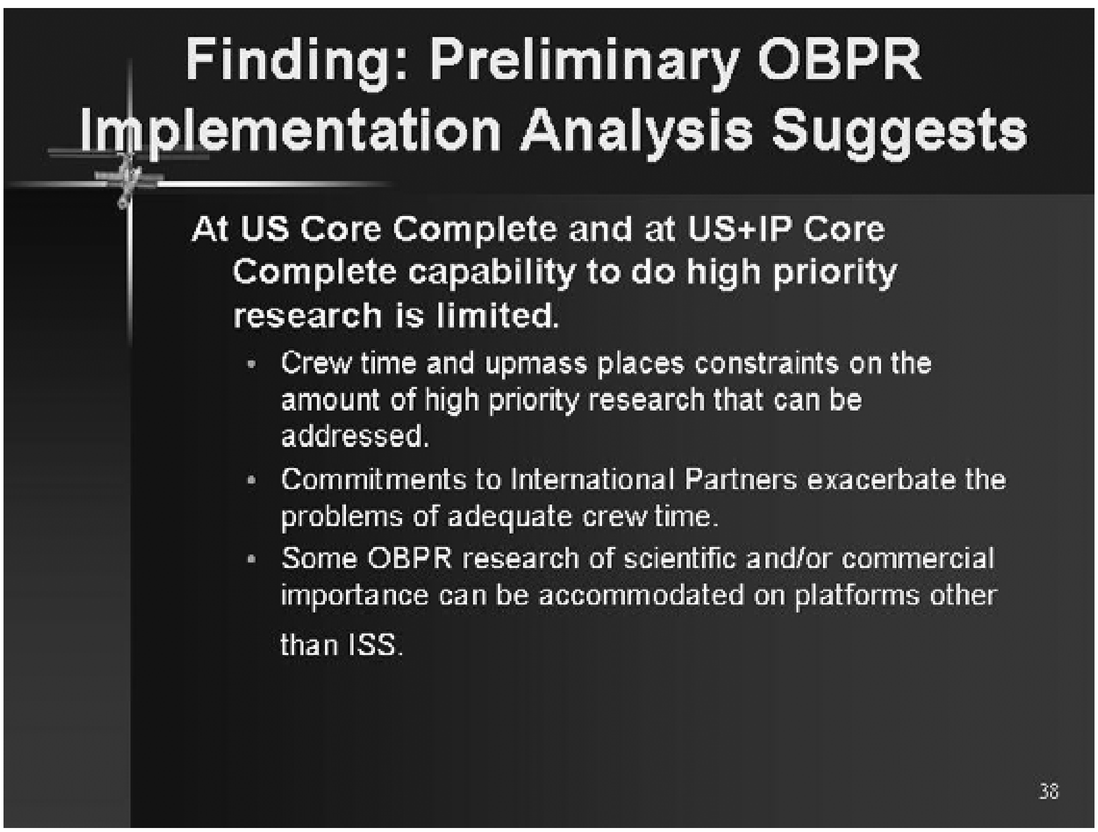
35

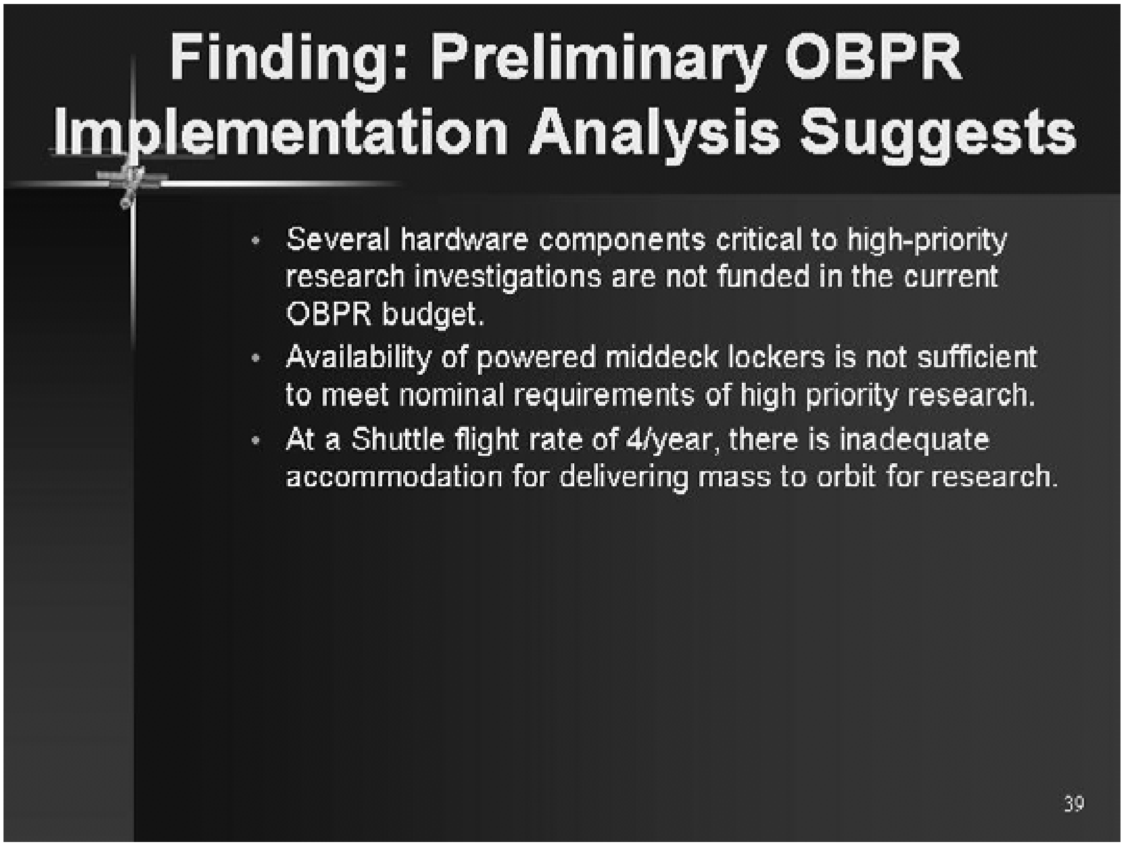
Pressurized Upmass Requirements by Research Priority

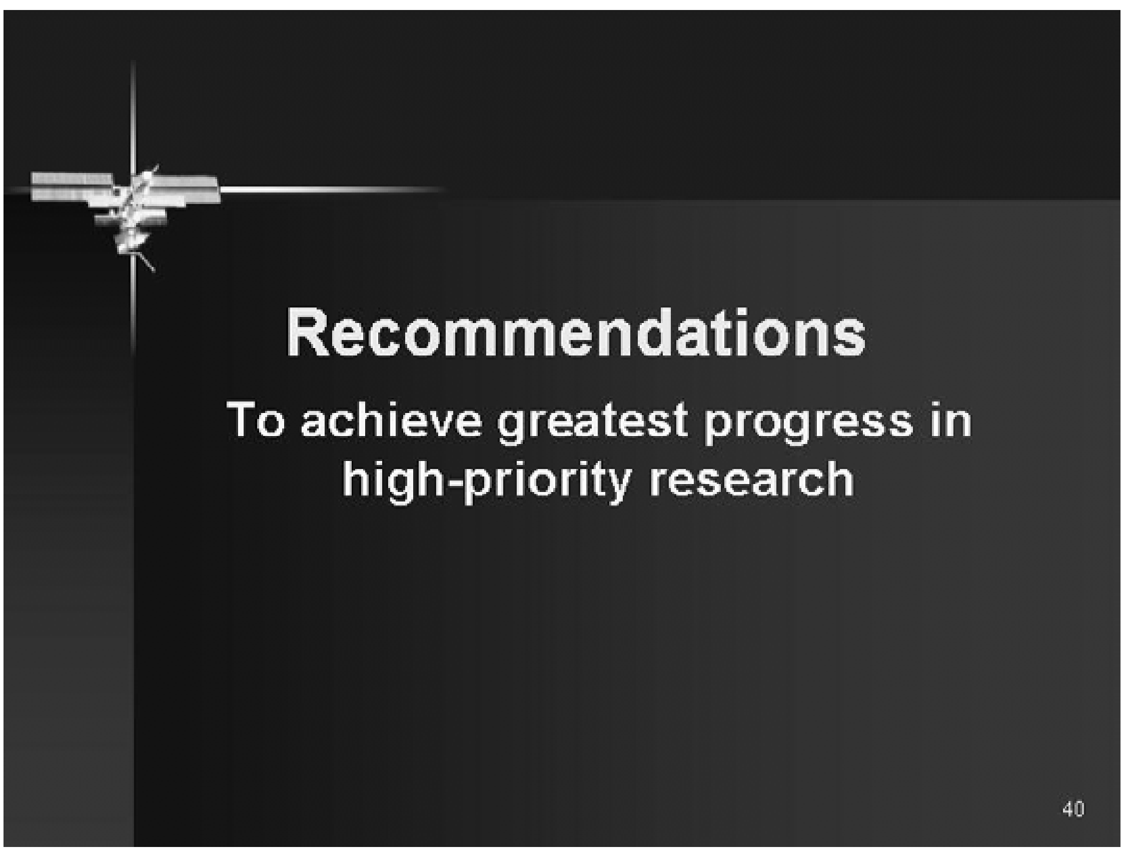


36


Crew Time Requirements by Research Priority
Crew Time (hours/week)
60
50
40
30
20
10
0
Enhanced
US Core Complete
US & IP Core Complete
1
2
3
4
5
6
Commercial
Priority Ranking
Nominal
Viable
37


Finding: Preliminary OBPR Implementation Analysis Suggests
At US Core Complete and at US+IP Core Complete capability to do high priority research is limited.
• Crew time and upmass places constraints on the amount of high priority research that can be addressed.
• Commitments to International Partners exacerbate the problems of adequate crew time.
• Some OBPR research of scientific and/or commercial importance can be accommodated on platforms other than ISS.
38


Finding: Preliminary OBPR Implementation Analysis Suggests
• Several hardware components critical to high-priority research investigations are not funded in the current OBPR budget.
• Availability of powered middeck lockers is not sufficient to meet nominal requirements of high priority research.
• At a Shuttle flight rate of 4/year, there is inadequate accommodation for delivering mass to orbit for research.
39


Recommendations
To achieve greatest progress in high-priority research
40

Recommendation: Science on ISS

If enhancements to ISS beyond "US Core Complete"[1] are not anticipated, NASA should cease to characterize the ISS as a science driven program.

Rationale:

- OBPR's implementation analysis suggested difficulties in implementing the high priority research given the current and near-term plan.
  - Crew time, resupply upmass and facilities are major factors.
- Other reasons for ISS include engineering achievement, space commercialization, international leadership, and classroom education.

1 See definition, Appendix C page 56

41

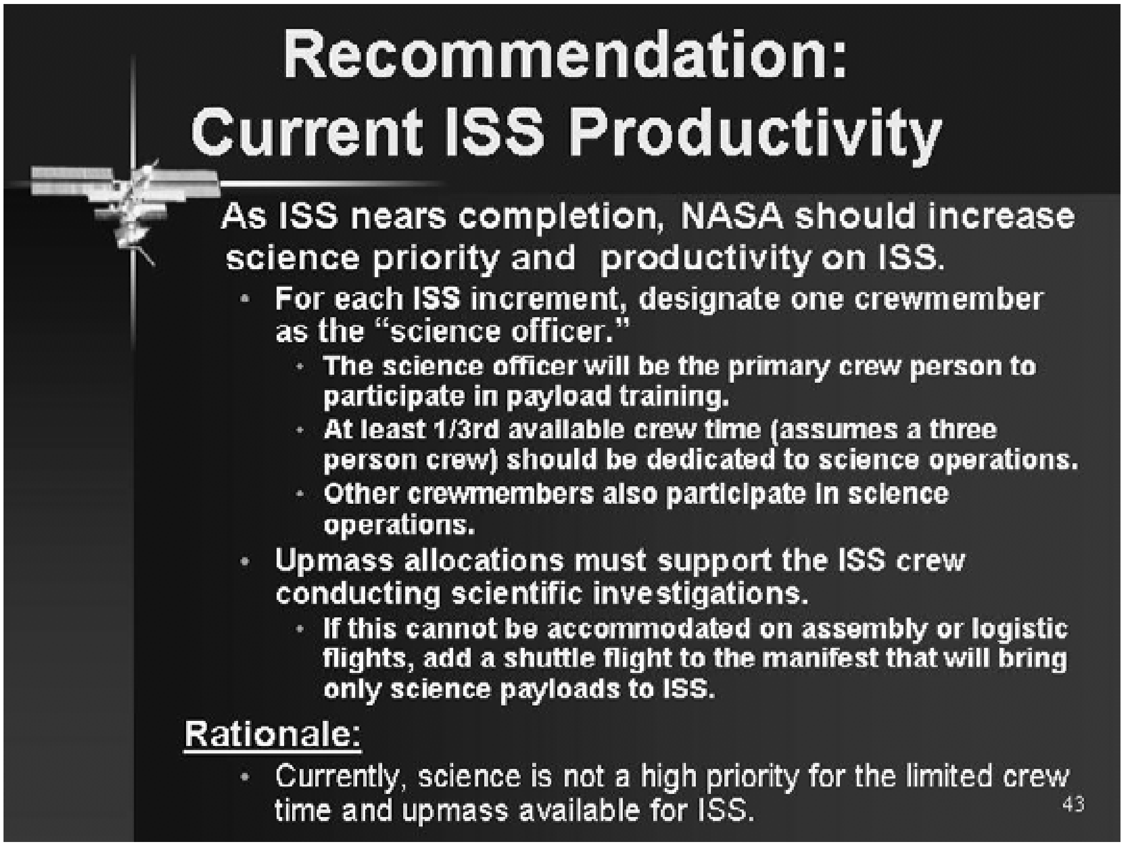
Recommendation: ISS Research Productivity

NASA must resolve the upmass and crew research time issue.

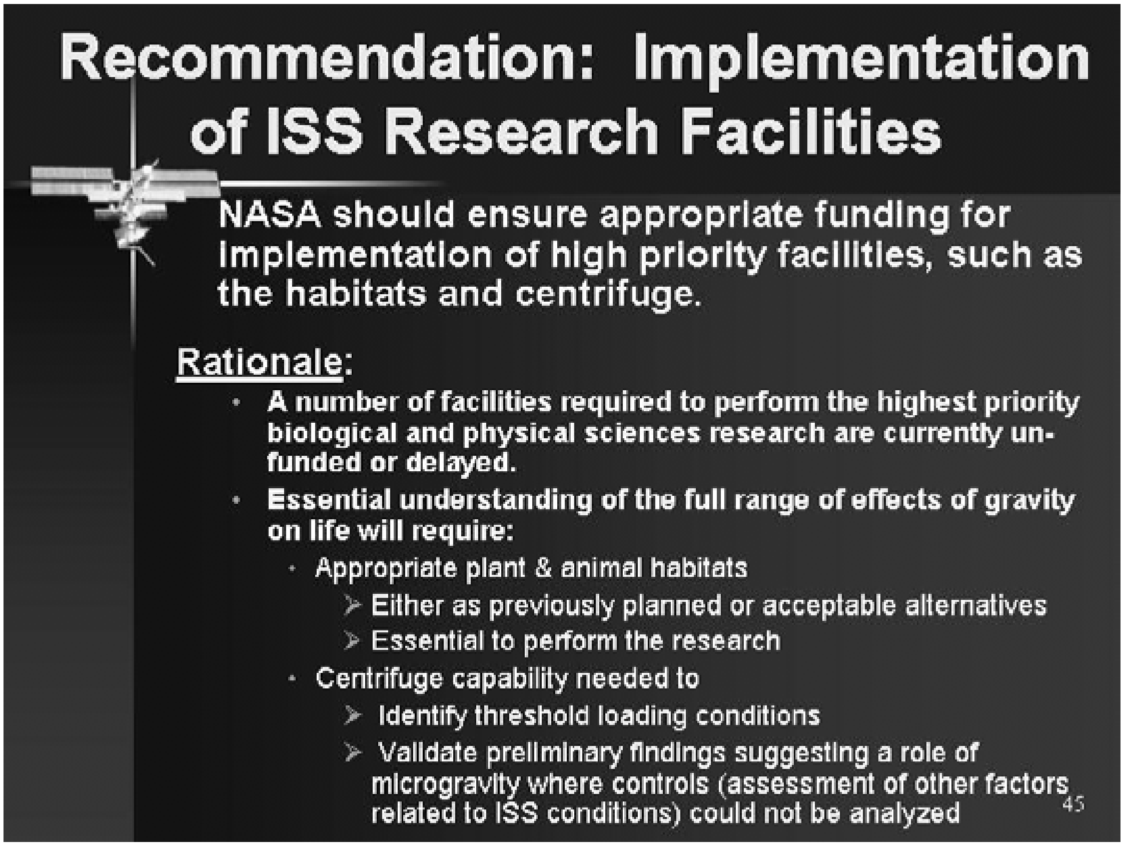
Rationale:

- Crew time and upmass were identified as one of the most severe restrictions on research productivity under both US and US + IP Core Complete configurations.
- IP barter agreements are based on research that requires greater than a 3 person crew.
- REMAP understands that NASA is examining crew time availability for research and encourages vigorous attention to this critical resource.

42


Recommendation:
Current ISS Productivity
As ISS nears completion, NASA should increase science priority and productivity on ISS.
• For each ISS increment, designate one crewmember as the "science officer."
• The science officer will be the primary crew person to participate in payload training.
• At least 1/3rd available crew time (assumes a three person crew) should be dedicated to science operations.
• Other crewmembers also participate in science operations.
• Upmass allocations must support the ISS crew conducting scientific investigations.
• If this cannot be accommodated on assembly or logistic flights, add a shuttle flight to the manifest that will bring only science payloads to ISS.
Rationale:
• Currently, science is not a high priority for the limited crew time and upmass available for ISS.
43


Recommendation:
Basic Research
OBPR should include, in its high-priority research portfolio, outstanding basic scientific research programs that address important questions in the physical and biological sciences, and which require long-term experiments on the ISS, based on their intrinsic scientific value.
Rationale:
• OBPR's research portfolio must be built around the most important scientific problems relevant to the NASA mission on the ISS, rather than covering representative sub-fields of science.
44


Recommendation: Implementation of ISS Research Facilities
NASA should ensure appropriate funding for implementation of high priority facilities, such as the habitats and centrifuge.
Rationale:
• A number of facilities required to perform the highest priority biological and physical sciences research are currently un-funded or delayed.
• Essential understanding of the full range of effects of gravity on life will require:
• Appropriate plant & animal habitats
➢ Either as previously planned or acceptable alternatives
➢ Essential to perform the research
• Centrifuge capability needed to
➢ Identify threshold loading conditions
➢ Validate preliminary findings suggesting a role of microgravity where controls (assessment of other factors related to ISS conditions) could not be analyzed
45


Recommendation: Fully Utilize Available Options for Space Research
NASA should consider additional Shuttle science/commercial flight opportunities.
• Investigate dedicated science and/or commercial flights on a regular basis.
• Guarantee flight opportunities
• Guarantee routine, repetitive access to space
• Investigate the possibility of auctioning rack space to gauge true market interest.
Rationale:
• Many science priorities do not need long duration in space.
• Many science priorities do need repetitive, routine access to space.
• NASA funding may impact market interest.
• Use of non-NASA funds to purchase a flight opportunity can be used as another indication of the value of the proposed space research.
46

Recommendation: Time to Orbit

NASA must reduce the time between experiment selection and flight for research investigations.

Rationale:

- Current long lead time discourages excellent researchers from proposing to NASA's programs.
- "Time to orbit" is a major commercial partner concern.
- Reasonably short times are essential if graduate students are to be involved.

47

Recommendation: Research Funding

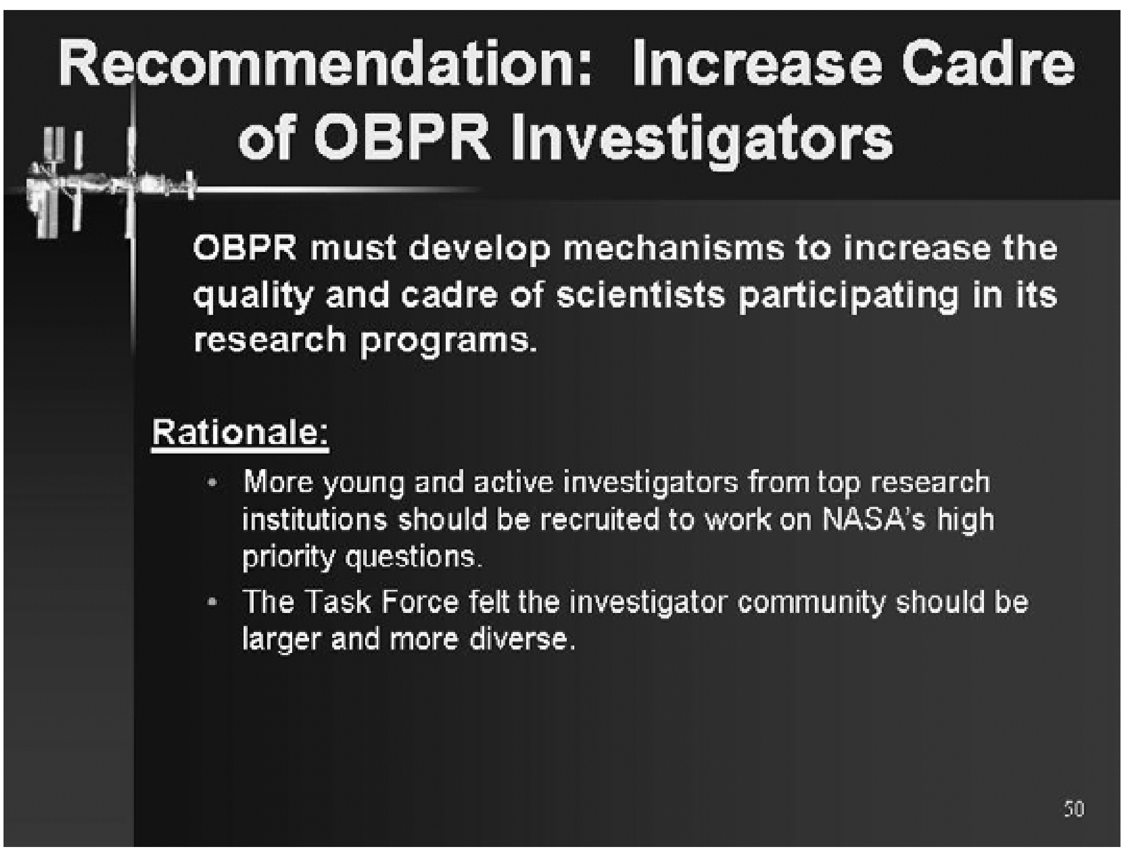
In order to attract high caliber scientists from a large national pool, NASA must assure science as a priority commitment with regard to flight schedule and project funding.

Rationale:

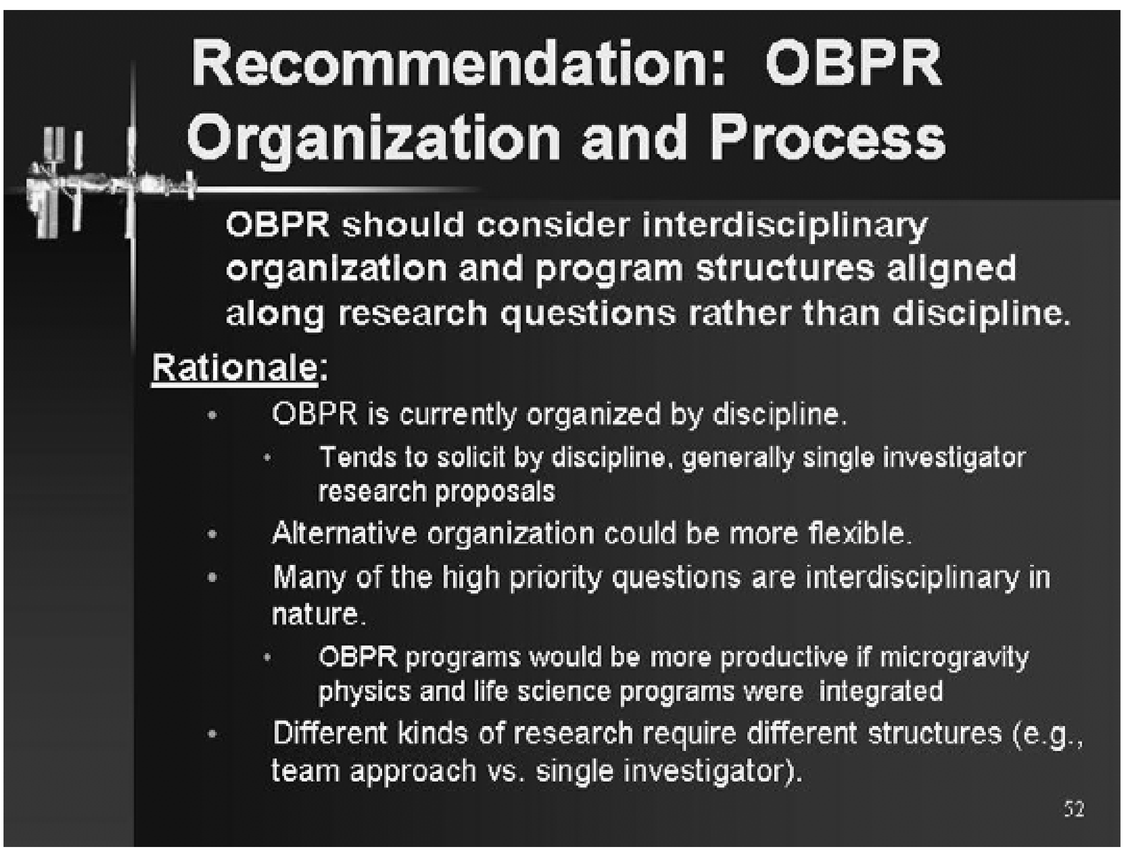
- Research funds have been diverted a total of 4 times to cover engineering overruns.
- Office of Space Flight indicated total research slippage for investigators has been as much as 4-5 years.

48


Recommendation: Methods for Research Solicitation
OBPR should consider alternative methods for research solicitation and recruiting of key performers.
Rationale:
Solutions for OBPR's goal-oriented, need-driven, research problems may be facilitated by alternative methods of solicitation and recruiting.
Project selection by peer review
• A consensus based approach
• Works best for individual PI science programs
• Works best for broad focus, science community driven
DARPA-style program management
• Can open new areas
• Serves to build communities
• Can support multi-investigator projects
• Works best for goal-oriented research
49


Recommendation: Increase Cadre of OBPR Investigators
OBPR must develop mechanisms to increase the quality and cadre of scientists participating in its research programs.
Rationale:
• More young and active investigators from top research institutions should be recruited to work on NASA's high priority questions.
• The Task Force felt the investigator community should be larger and more diverse.
50


Recommendation:
Science Leadership
OBPR scientists should ensure the development of a visionary strategic research program that is focused on the problems whose solutions will further the NASA mission.
Rationale:
• Development of a strategic, goal oriented program will enable selection of the best research to facilitate space exploration and fundamental science.
51


Recommendation: OBPR
Organization and Process
OBPR should consider interdisciplinary organization and program structures aligned along research questions rather than discipline.
Rationale:
• OBPR is currently organized by discipline.
• Tends to solicit by discipline, generally single investigator research proposals
• Alternative organization could be more flexible.
• Many of the high priority questions are interdisciplinary in nature.
• OBPR programs would be more productive if microgravity physics and life science programs were integrated
• Different kinds of research require different structures (e.g., team approach vs. single investigator).
52

Recommendation: Coordinating Research Efforts

OBPR life sciences strategy should integrate multiple levels of analysis, (i.e., organismal, systemic, cellular, molecular).

OBPR physical sciences strategy should coordinate the research efforts from Fundamental Microgravity, Engineering, Commercial Engineering, and Technology Development where it makes sense.

Examples: combustion, fire safety

Rationale:

- Coordinated strategies focused on specific problems would optimize research productivity.

53

Recommendation: Potential New Lines of Research

OBPR should examine potential lines of research outside of the current research portfolio.

Rationale:

- REMAP Task Force prioritized only the current research portfolio.

54

Recommendation: Metrics

Given that NASA has multiple requirements for producing and reporting productivity metrics, the purpose of each metric should be clearly delineated such as science productivity, education outreach, and public affairs.

Rationale:

- **Specific metrics, even when accurate, do not necessarily index the measure of interest. For example, media attention is not suitable for evaluation of scientific quality.**

55

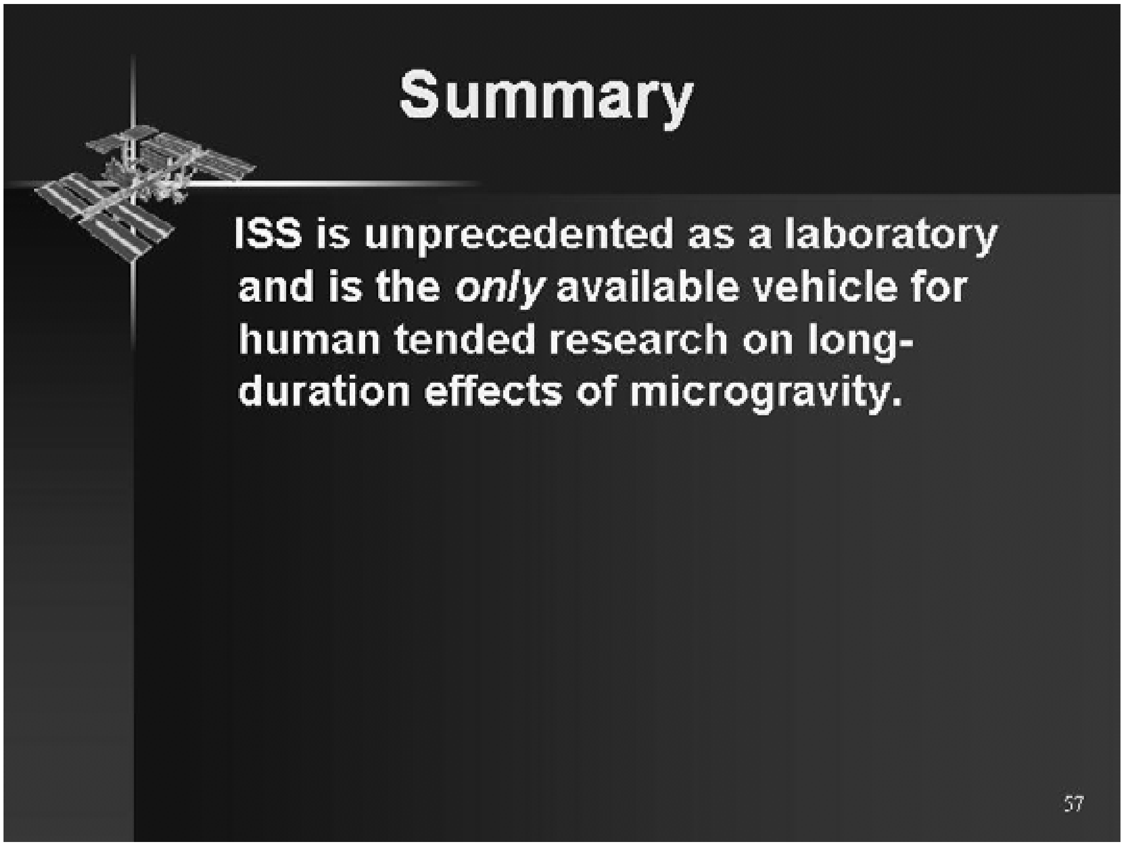
Recommendation: Coordination with International Partners

NASA should continue coordination of facilities development and research solicitations with the International Partners, and attempt to address the International Partner concerns.

Rationale:

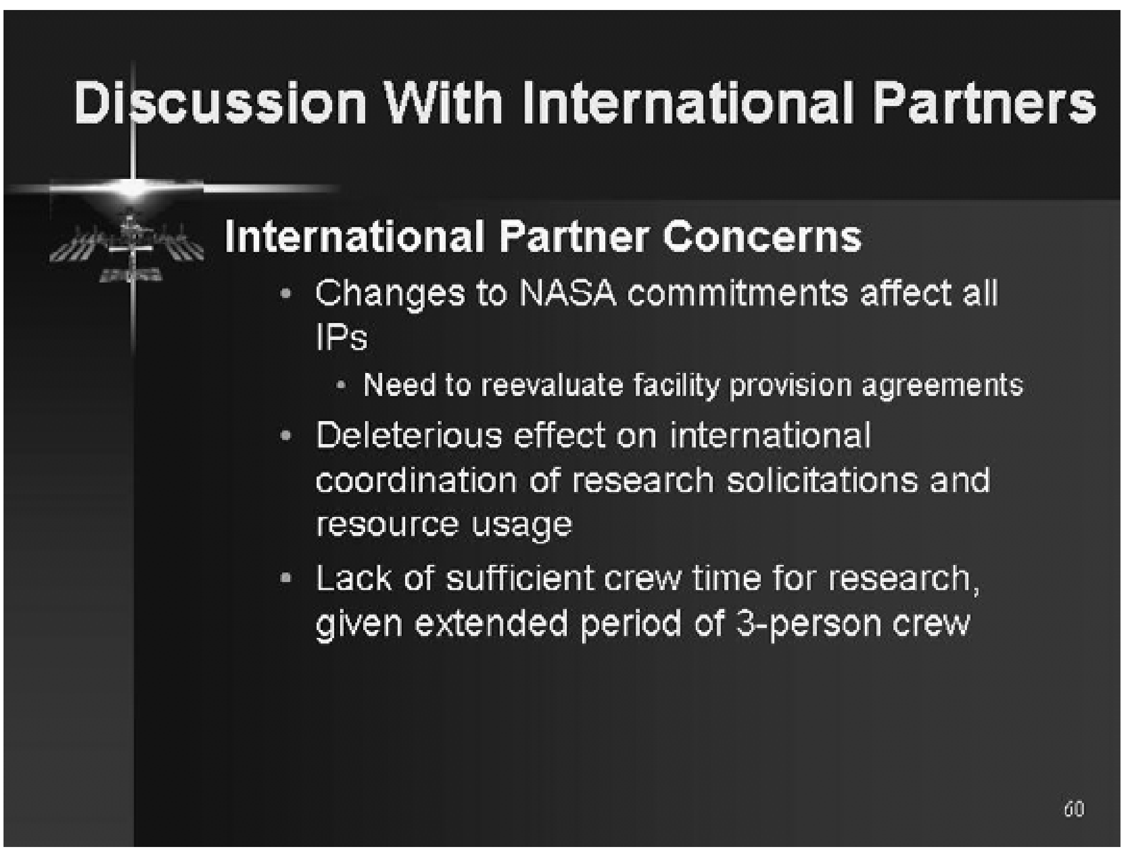
- IPs have chosen to build certain ISS research facilities and not others to avoid replication based on understanding of shared facility utilization
- IPs have continued interest in coordination with NASA and submitted analyses of their priorities and concerns to REMAP

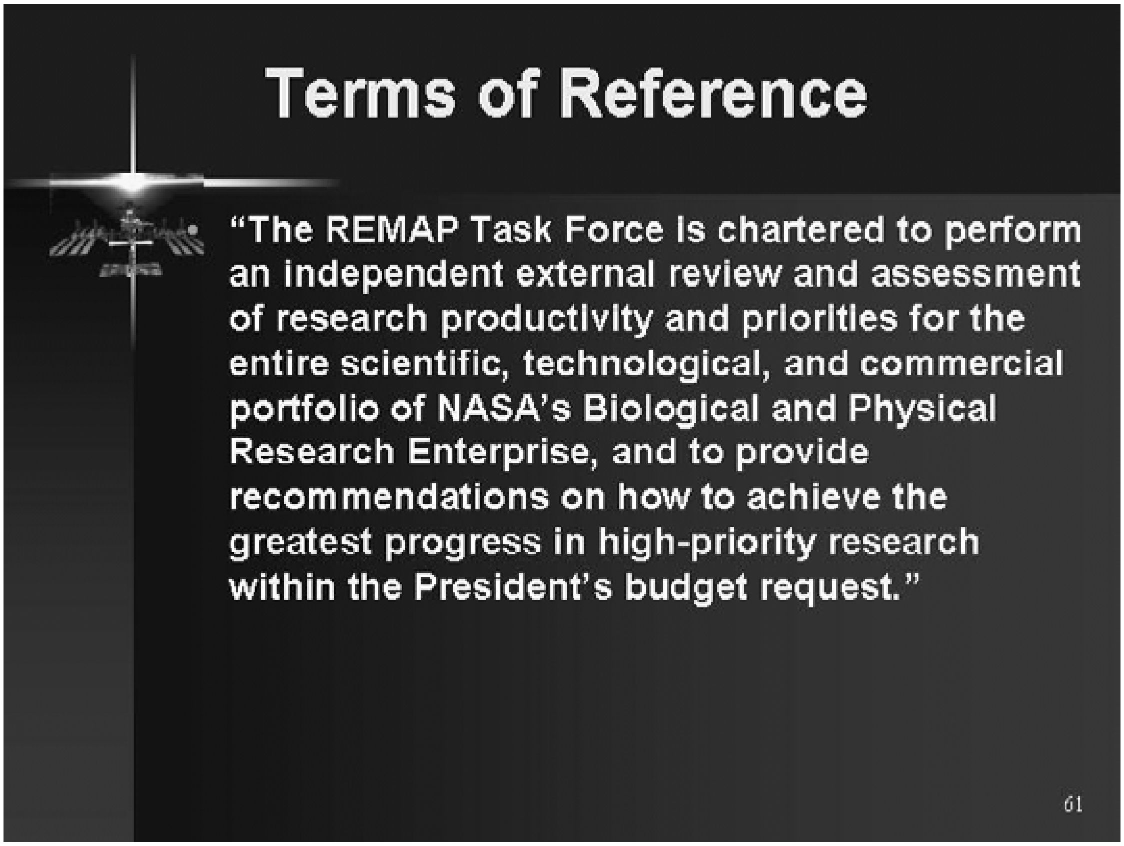
56

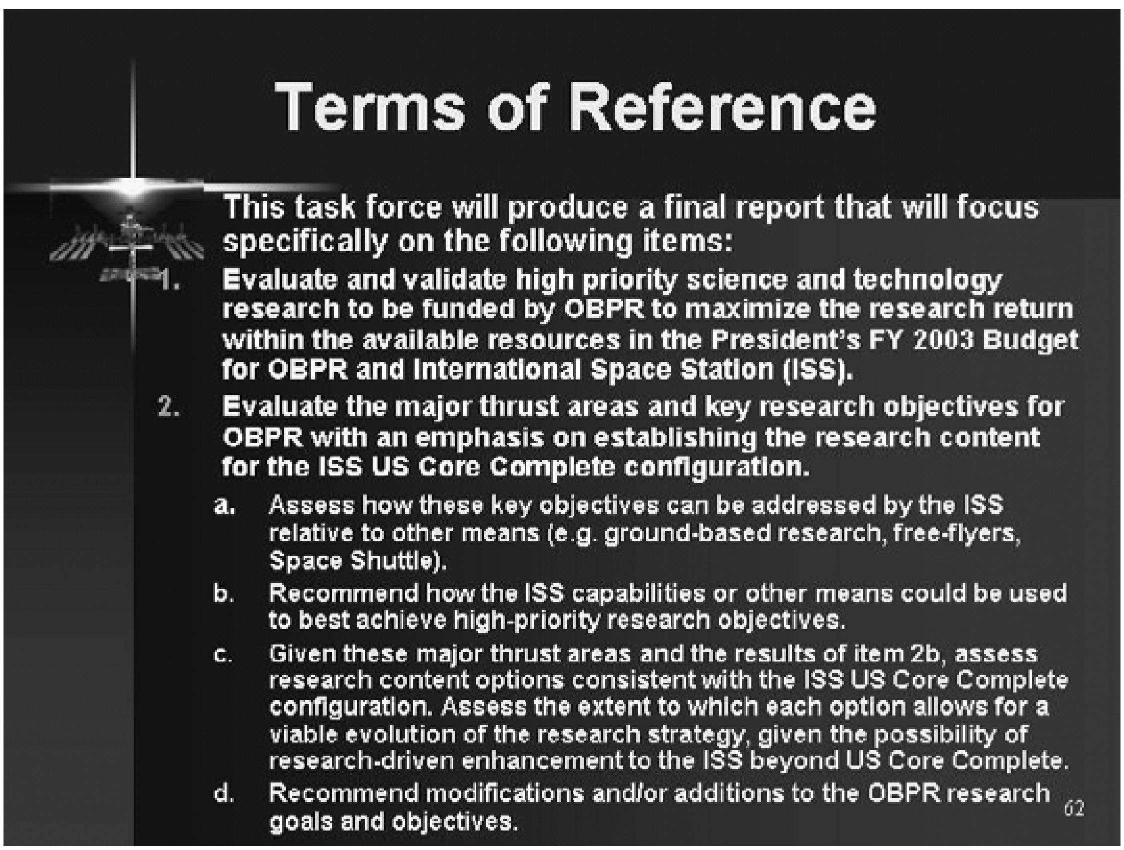

Summary
ISS is unprecedented as a laboratory and is the *only* available vehicle for human tended research on long-duration effects of microgravity.
57

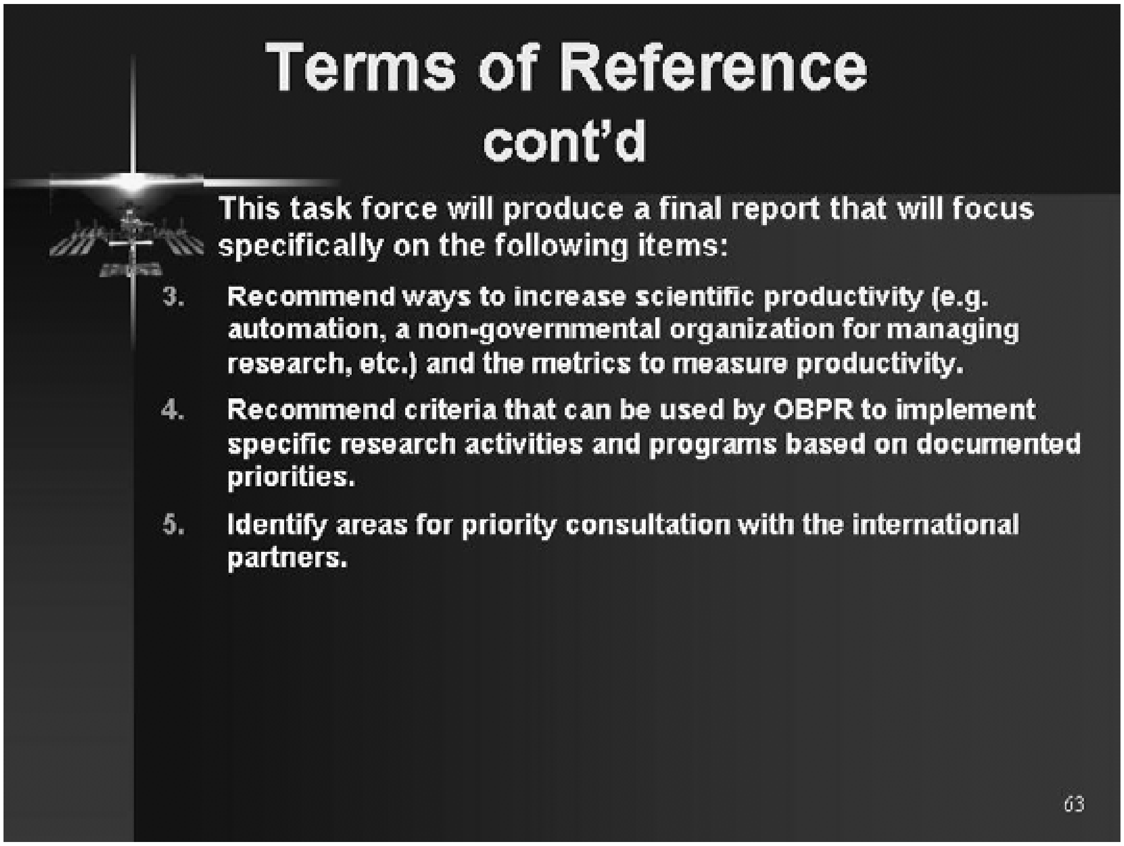

Appendices
58

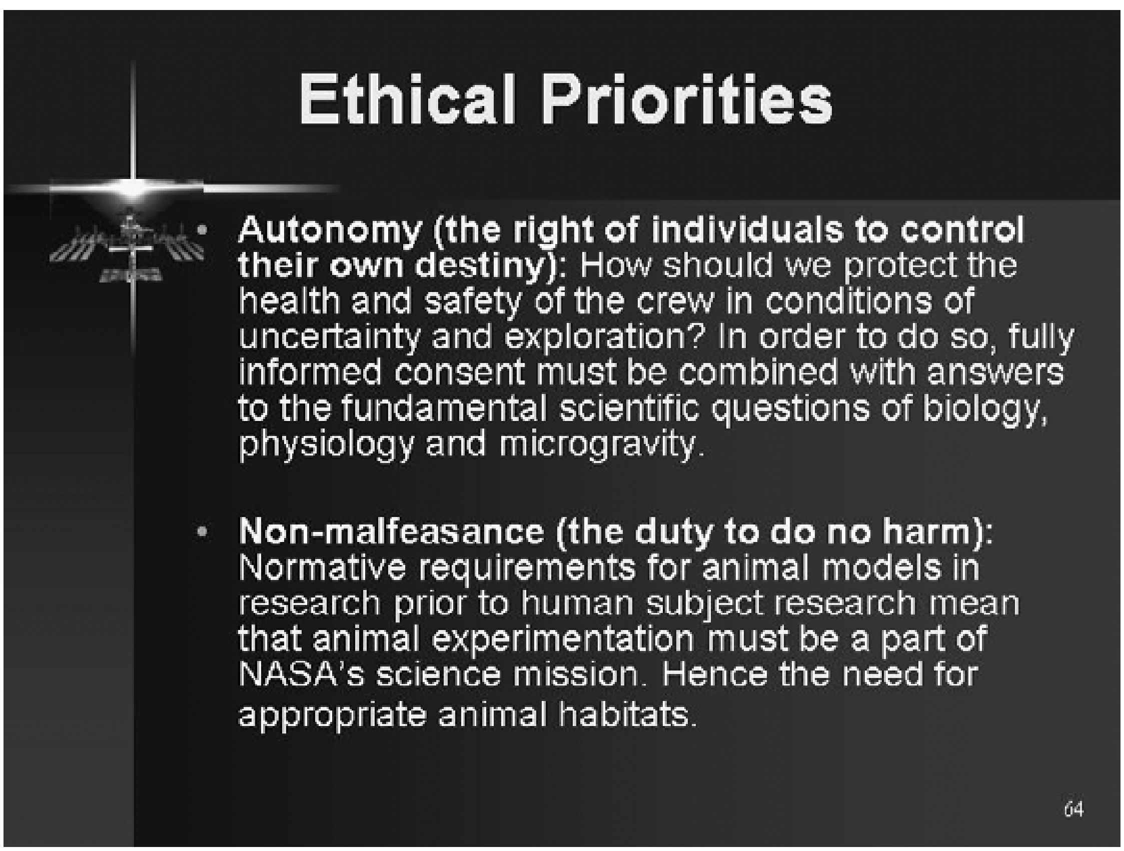

Discussion With International Partners
IP Priorities
CSA (no specific priority order)
Earth and the environment
ISS utilization
Mars exploration
Small satellites
ESA Priorities
Benefit to Humans on Earth
NASDA Priorities
Microgravity Science
Space biology
Space medicine
59


Discussion With International Partners
International Partner Concerns
Changes to NASA commitments affect all IPs
Need to reevaluate facility provision agreements
Deleterious effect on international coordination of research solicitations and resource usage
Lack of sufficient crew time for research, given extended period of 3-person crew
60


Terms of Reference
• "The REMAP Task Force is chartered to perform an independent external review and assessment of research productivity and priorities for the entire scientific, technological, and commercial portfolio of NASA's Biological and Physical Research Enterprise, and to provide recommendations on how to achieve the greatest progress in high-priority research within the President's budget request."
61


Terms of Reference
This task force will produce a final report that will focus specifically on the following items:
1. Evaluate and validate high priority science and technology research to be funded by OBPR to maximize the research return within the available resources in the President's FY 2003 Budget for OBPR and International Space Station (ISS).
2. Evaluate the major thrust areas and key research objectives for OBPR with an emphasis on establishing the research content for the ISS US Core Complete configuration.
a. Assess how these key objectives can be addressed by the ISS relative to other means (e.g. ground-based research, free-flyers, Space Shuttle).
b. Recommend how the ISS capabilities or other means could be used to best achieve high-priority research objectives.
c. Given these major thrust areas and the results of item 2b, assess research content options consistent with the ISS US Core Complete configuration. Assess the extent to which each option allows for a viable evolution of the research strategy, given the possibility of research-driven enhancement to the ISS beyond US Core Complete.
d. Recommend modifications and/or additions to the OBPR research goals and objectives.
62


Terms of Reference
cont'd
This task force will produce a final report that will focus specifically on the following items:
3. Recommend ways to increase scientific productivity (e.g. automation, a non-governmental organization for managing research, etc.) and the metrics to measure productivity.
4. Recommend criteria that can be used by OBPR to implement specific research activities and programs based on documented priorities.
5. Identify areas for priority consultation with the international partners.
63


Ethical Priorities
• Autonomy (the right of individuals to control their own destiny): How should we protect the health and safety of the crew in conditions of uncertainty and exploration? In order to do so, fully informed consent must be combined with answers to the fundamental scientific questions of biology, physiology and microgravity.
• Non-malfeasance (the duty to do no harm): Normative requirements for animal models in research prior to human subject research mean that animal experimentation must be a part of NASA's science mission. Hence the need for appropriate animal habitats.
64

Ethical Priorities

- **Justice (fairness, access to, and equitable distribution of resources held in common):** This must be a priority goal. What makes a particular scientific pursuit worth our attention? Does it advance a common good?
- **Beneficence (working for the best interests of the public):** What makes good science "good"? One component must be attention to the role of social value and democratic civil discourse in science policy, from basic to applied science.
- **Solidarity (agreement among representative bodies and concerned parties):** Hence the need for the REMAP process of interdisciplinary science review.

65

Minority Opinion: Acrivos

I have read in detail the material which you sent me yesterday. Some of the statements in the Executive Summary as well as in the Power Point presentation I strongly support, e.g. the statement that " If enhancements to the ISS beyond US core complete are not anticipated, NASA should cease to characterize the ISS as a science driven program." Others, I could live with, but there are numerous parts that I disagree with. The trouble is that, as some of us indicated to no avail several weeks ago, the present draft of the X-Summary and of the presentation is strongly slanted towards the Biological/Medical areas, with the Physical Sciences appearing as a mere Appendix which, presumably could be removed surgically at the first opportunity (c.f. the first page of the X-Summary and slide #25). I have several other concerns but the one noted above is the main one.

Thus I cannot support the Draft in its present form.

66

Minority Opinion: Metcalf

Please be sure to indicate my lack of concurrence with this presentation. The reasons, as I have said several times before, are that it contains nothing of the atomic physics aspects that are such a vital part of NASA's activities. For example, deep space navigation will never occur without improved clocks, and development of these needs the ISS. Fountain clocks will never work well enough. Other vital topics that are missing, in spite of their important role in NASA's research activity and their need for the ISS environment, are Bose-Einstein condensation, laser cooling, and critical phenomena (this is more universal than even some of the atomic physics). Furthermore, the error I tried to correct many times, namely "phase transitions", not "phase transformation", has reappeared - I don't know why there is insistence on something demonstrably wrong. This is not the way for an impartial committee to proceed.

67

Dissent as Requested: Jones

As a member of the OBPR Research Maximization and Prioritization (REMAP) Task Group I wish to express my concerns about:

1. The process by which priorities for microgravity research programs were assigned, and

2. The ranking given to the protein crystallization program.

68

APPENDIX D: Previous Reports to NASA on OBPR Science

Bioastronautics and Fundamental Space Biology

1. A Strategy for Space Biology and Medical Sciences for the 1980s and 1990s, Committee on Space Biology and Medicine, Space Science Board, NRC, 1987
2. Assessment of Programs in Space Biology and Medicine, Committee on Space Biology and Medicine, Space Studies Board, NRC, 1991
3. Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies, National Academy Press 1996
4. Advanced Technology for Human Support in Space, NRC, Aeronautics and Space Engineering Board, Committee on Advanced Technology for Human Support in Space, 1997.
5. A Strategy for Research in Space Biology and Medicine in the New Century, NRC, Space Studies Board, Committee on Space Biology and Medicine, 1998
6. Future Biotechnology Research on the International Space Station, Space Studies Board, NRC, Nat'l Acad. Press, 2000
7. Review of NASA's Biomedical Research Program, NRC, Space Studies Board, Committee on Space Biology and Medicine, 2000
8. Safe Passage: Astronaut Care for Exploration Missions, IOM, Board on Health Sciences Policy, Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit, 2001.

Physical Sciences

1. Toward a Microgravity Research Strategy. Committee on Microgravity Research, Space Studies Board, NRC, 1988
2. Space Science in the Twenty-First Century: Imperatives for the Decades 1995 to 2015—Fundamental Physics and Chemistry, Task Group on Fundamental Physics and Chemistry, Space Studies Board, NRC,1988
3. Microgravity Research Opportunities for the 1990's, Space Studies Board, Commission on Microgravity Research, NRC, 1995
4. Future Materials Science Research on the International Space Station, National Materials Advisory Board, NRC, 1997.
5. Microgravity Research in Support of Technology for the Human Exploration and Development of Space and Planetary Bodies, Space Studies Board, NRC, 2000
6. Future Biotechnology Research on the International Space Station, National Academy Press 2000
7. The Mission of Microgravity and Physical Sciences Research at NASA, NRC, 2000
8. Readiness Issues Related to Research in the Biological and Physical Sciences on the International Space Station, Space Studies Board (Phase 1 Report TGRISS 2001)

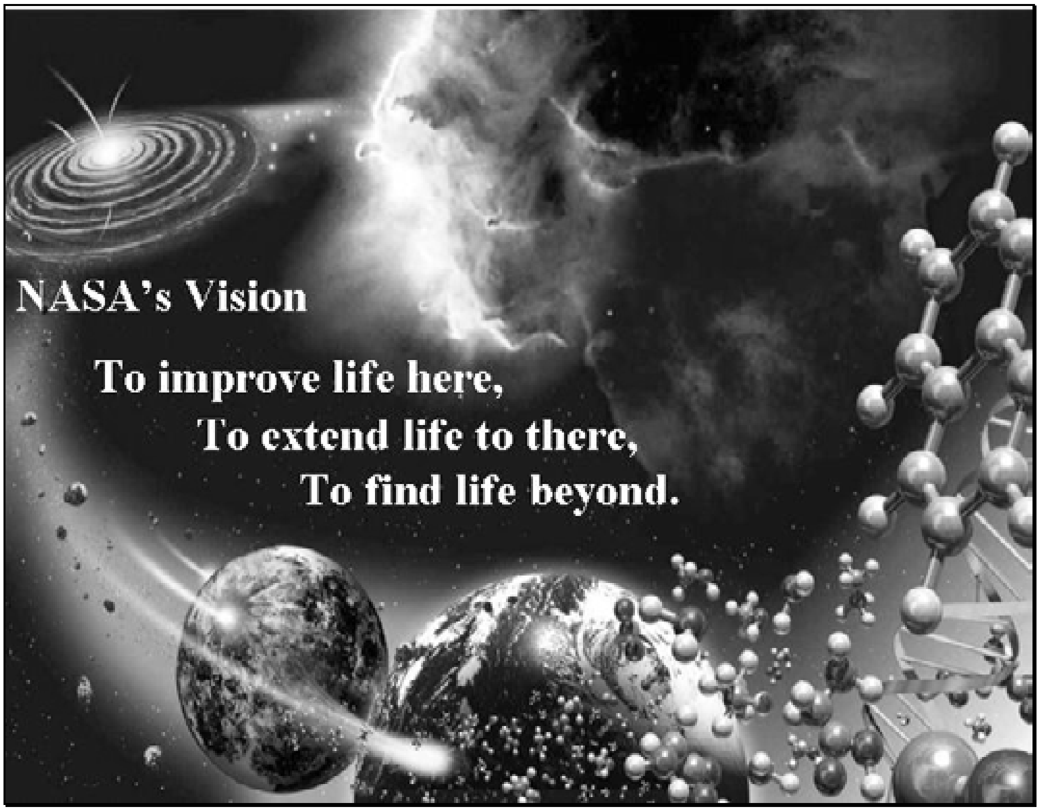
Space Product Development

1. A Review of the Centers for the Commercial Development of Space: Concept and Operation, National Academy of Public Administration (NAPA) 1994
2. Engineering Research and Technology Development on the Space Station, National Research Council, 1996
3. The International Space Station Commercialization Study, Potomac Institute for Policy Studies, 1997
4. Reflections on the Commercial Space Center (CSC) Program, National Academy of Public Administration, June, 1998.
5. Commercial Space Act, 1998. Public Law 105-303.
6. NASA: Commerce and the International Space Station, KPMG report, November, 1999. Report available on-line at http://commercial.hq.nasa.gov
7. Future Biotechnology Research on the International Space Station, Space Studies Board, Task Group for the Evaluation of NASA's Biotechnology Facility for the International Space Station, Space Studies Board, NRC, 2000
8. X-ray Crystallography Facility at the Center for Biophysical Sciences and Engineering, University of Alabama at Birmingham, (2000), prepared by an external review panel commissioned by NASA management

Setting Science Priorities

1. Setting Priorities for Space Research: Opportunities and Imperatives, National Academy Press, 1992
2. Setting Priorities for Space Research: An Experiment in Methodology, National Academy Press, 1995
3. Institutional Arrangements for Space Station Research, Aeronautics and Space Engineering Board, Space Studies Board, NRC, 1999
4. Setting Priorities and Coordinating Federal R&D Across Fields of Science: RAND: A Literature Review; Executive Summary and Annotated Bibliography, National Science Board DRU-2286/1-NSF, April 2000
5. Federal Research Resources: A Process for Setting Priorities, National Science Board, October 11, 2001
6. Federally Funded Research: Decisions for a Decade, U. S. Congress, Office of Technology Assessment, OTA-SET-490 (Washington, DC: U. S. Government Printing Office, May 1991) Chapter 5, Priority Setting in Science
7. NASA Decadal Plan, NASA, 2000

APPENDIX E: NASA Vision and Mission



The NASA Mission

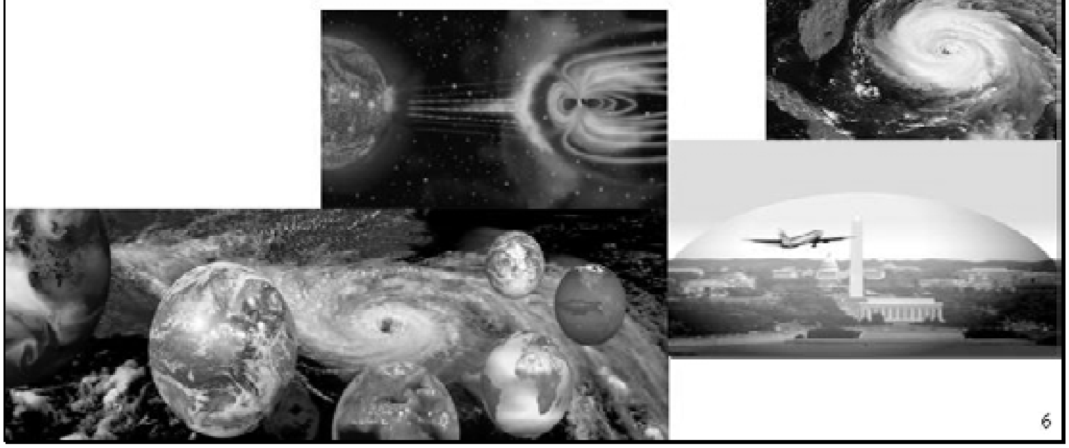
To understand and protect our home planet
To explore the Universe and search for life
To inspire the next generation of explorers

... as only NASA can.

5

To Understand and Protect Our Home Planet

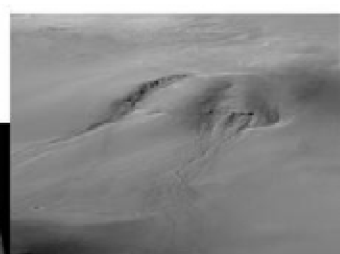
- Understanding the Earth's system and its response to natural and human-induced changes
- Enabling a safe, secure, efficient, and environmentally friendly air transportation system
- Investing in technologies and collaborating with others to improve the quality of life and to create a more secure world

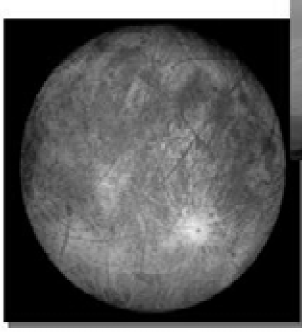


6

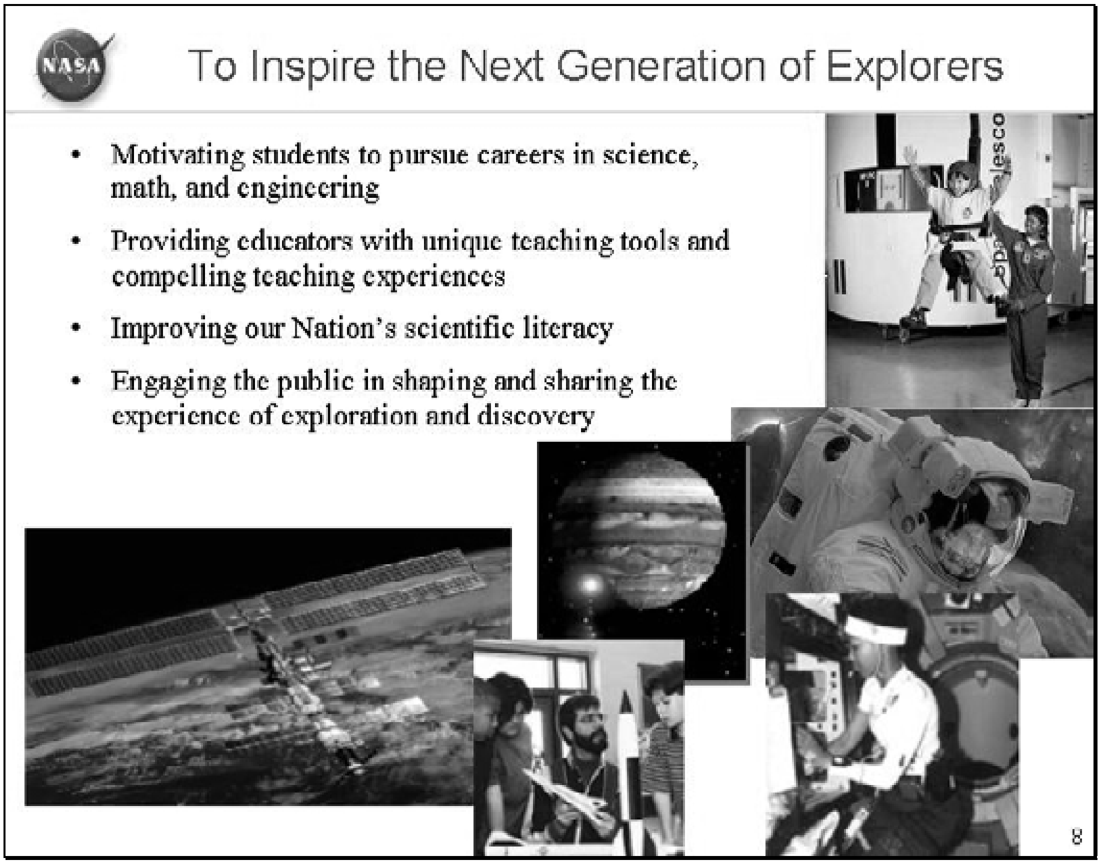
To Explore the Universe and Search for Life

- Exploring the Universe and the life within it… enabled by technology, first with robotic trailblazers, and eventually humans… as driven by these compelling scientific questions:
  - How did we get here?
  - Where are we going?
  - Are we alone?





7


NASA
To Inspire the Next Generation of Explorers
• Motivating students to pursue careers in science, math, and engineering
• Providing educators with unique teaching tools and compelling teaching experiences
• Improving our Nation's scientific literacy
• Engaging the public in shaping and sharing the experience of exploration and discovery
8

APPENDIX F: ReMAP Task Force Meeting with the International Partners

Representatives from NASA, CSA, ESA, and NASDA met with members of the ReMAP Task Force IP Subcommittee on April 19, 2001 to develop an understanding of International Partner (IP) priorities. The objectives of the meeting were to help determine capabilities NASA does and does not have in its priority areas of research, and to help understand the international nature of the ISS research program from experiment recruitment through implementation. The international nature of research is based on two premises: 1) IPs chose to build certain ISS research facilities and not build others based on the understanding that IPs would share facility utilization and avoid replication, and 2) IPs would coordinate biological and physical research solicitations (internationally). The IPs were given the action to answer the following questions:

- Why is the International Space Station necessary for research?
- What research requires a short-term mission and what research necessitates a long-term mission in space?
- What are the research areas in which use of the Centrifuge on the ISS is important?

The responses from the IPs (CSA, ESA, and NASDA) were reviewed by the ReMAP Task Force and are provided in this appendix.

Meeting Minutes

<u>Attendees:</u>

ReMAP IP Subcommittee:
Rae Silver
Andreas Acrivos
Mary Jane Osborn
Jim Pawelczyk

NASA:
Lisa Guerra
Louis Ostrach
Bradley Carpenter
Rebecca Spyke Gardner

National Space Development Agency of Japan (NASDA)
Masato Koyama (presenter)

Canadian Space Agency (CSA):
Alan Mortimer (presenter)
John Marrone
Heinz Gindl
Graham Gibbs

European Space Agency (ESA)
Karl Knott (presenter)
Ian Pryke

IP Presentations

- CSA outlined the following as their national space priorities (in no particular order):
    - Earth and the environment
    - ISS utilization
    - Mars exploration
    - Small satellites
- ESA gave an informal presentation and will follow up with a formal written report to the ReMAP Task Force in May.
    - ESA's main goal in space research is to benefit humans on Earth.
    - There is no prioritization of research disciplines at present.
- NASDA said that the following research fields will be emphasized in the merger of Japan's three space agencies (NASDA, National Aerospace Laboratory, and Institute for Space and Aeronautical Science):
    - Microgravity Science
    - Space Biology
    - Space Medicine

International Coordination and Concerns

- CSA, ESA, and Japan have chosen to build certain ISS research facilities and not build others based on the understanding that IPs would share facility use to avoid facility replication. Changes in NASA commitments to facility provision would therefore affect all IPs.
- CSA, ESA, NASDA, and NASA internationally coordinate biological and physical research solicitations.
    - Research proposals undergo an international peer review process. The international peer review process ensures world-class science selection.
    - One agency's research proposal may use another agency's facility through the international cooperation process.
    - Cancellation of one partner's facilities therefore affects research sponsored by other partners.
    - Reduced ISS resources (e.g., crew time, upmass, etc.) will significantly reduce international research capabilities and may jeopardize continued IP participation.

The main IP concern is lack of crew time for research given a three-person crew for an extended period.

CSA Report

CANADIAN SPACE AGENCY

Further to discussions with the NASA Research Maximization and Prioritization Task Force, the Canadian Space Agency (CSA) wishes to provide input on three issues identified in our presentation to the committee on April 19, 2002.

International Cooperation for the Scientific Utilization of International Space Station (ISS)

From the outset the CSA has developed programs based on a collaborative international approach. The CSA has seen international collaboration as the most efficient and effective way to reach national goals within the budget that has been allotted. International cooperation does, however, mean that the CSA has chosen not to build certain experimental hardware that would support very high priority science objectives. At the same time, the CSA has agreed to provide to the international community hardware that is of less strategic importance nationally, components required by the overall international scientific community as part of a complete science laboratory. This is especially important for life sciences. For example, the CSA decided not to develop rodent facilities for ISS, seen as one of the highest priorities nationally, and has agreed to provide the Insect Habitat, which is of great scientific value, but which has much lower national priority.

Other Agencies have made similar decisions. Both the European Space Agency (ESA) and NASA have agreed not to build duplicate hardware for the study of human physiology and to integrate the hardware into a single laboratory co-located within the ISS. Further, early discussions amongst all ISS partners reached an agreement to build only one combustion facility so that resources could be used to build other microgravity facilities.

International cooperation in the scientific utilization of ISS has led to a shared international equipment set that allows all partners to meet their scientific objectives, making best use of the resources on ISS in an efficient and continuous manner. However, no partner will be able to meet even their high priority scientific objectives unless all agencies provide the research elements that have been mutually agreed.

International cooperation extends beyond a coordinated research facility. Currently experiments to be performed on ISS are solicited jointly by all partners using the same announcement and background information. Proposals submitted by scientists from all partner countries are reviewed by the same international peer review panel. Selection for flight is the responsibility of an international steering committee. Once selected, experiments are prepared for flight with the oversight of international implementation committees that follow progress and can make adjustments to maximize the science return to all partner agencies.

International integration of the scientific utilization of ISS has been implemented at all stages. Not only does it provide an excellent example of international cooperation, the sharing of resources and responsibility has provided the most effective approach to the maximizing of scientific return for all ISS partners.

The coordinated scientific approach benefits from the resultant, multi-national scientific teams, allowing more rapid advance in the depth and range of our knowledge.

Utilization of ISS

The CSA views the ISS as the only platform for a variety of scientific investigations. In particular:

ISS provides the only opportunity for long duration microgravity experiments:
This is good for protein crystal growth, semi-conductor crystal growth, diffusion studies, multi-generation studies of animals, radiation biology in space, physiological adaptation of humans and animals and the study of cumulative effects in both biological and physical disciplines.

ISS is human-tended:
Astronauts are required for studies in human physiology, (bone loss, cardiovascular system, radiation studies) and psychology. Astronauts allow real-time iteration of experiments in response to unexpected results, human observation of experiments and interaction with investigators. Some processes require human intervention, such as animal care over extended periods or particularly delicate manipulations.

ISS provides frequent access and experiment repetition:
ISS allows repetition and iteration of experiments within a reasonable time. This will increase the scientific rigor of the research (by increasing the experimental sample size) and allow advances to be made in the timeframe required so that the results can impact terrestrial research priorities.

Large payloads can be accommodated by ISS:
Sophisticated payloads such as Fluid Science Laboratory or the Centrifuge cannot be accommodated on most free flyers.

Transport to/from ISS is generally gentle compared to other vehicles:
When compared with free flyer options, launch and landing are relatively gentle. This is important in order to preserve protein and other crystals grown in space and to have less impact on live specimens.

Scientific Priorities

From the outset, the CSA science programs have worked on the premise that "We cannot be all things to all people". The program has taken a focused approach to scientific research in space. Research directions have been selected with the advice of standing advisory committees and input from the wider scientific community through workshops.

Priorities have been based upon:

Areas of national priority

Areas of national excellence
Niches where Canada can significantly advance the international scientific effort
Areas with benefits on Earth

This process has led to identification of the following research areas:

Life Sciences:

Bone and Muscle Loss
- Significant in space, particularly for long term flight
- Relevant on earth particularly in processes of aging

Cardiovascular and Metabolic Physiology
- Important and for long duration flights and return to Earth
- Significant in study of heart disease and metabolic disorders

Radiation
- Area of national excellence
- Critical for long duration space missions
- Directly impacts radiation safety and cancer treatment on Earth

Neuroscience
- Long history in space research in Canada
- Wide range of applications to conditions associated with aging on Earth
- Significant applications to operational considerations during spaceflight

Isolation and Multi-cultural Psychology
- An area of significant national expertise and national pride
- Critical for long duration spaceflight
- Assists in many applications on Earth

Microgravity Sciences:

Materials Science
- Mechanisms, basic physical properties and fundamental issues
- The goal is to improve processes and products on Earth

Fluid Science
- Study of the motion or structure of fluids
- Use spaceflight of physical properties and processes affected by gravity

Biotechnology
- Study of the structure and behavior of non-living organic material
- Protein crystallization for development of structures on Earth with biomedical application

The centrifuge is a critical scientific element for the ISS

ISS partners have developed a plan for providing a set of experimental hardware, which will allow the best science from around the world to be performed on the ISS. The centrifuge is central to our ability to obtain scientific results that will be accepted by the international scientific community. The centrifuge provides the control; the comparison, to determine the changes caused by the weightless environment. A control is clearly essential in the design of animal experiments. In fact most ISS hardware has been built to make use the centrifuge for control samples. The centrifuge is however also critical for cell biology and plant biology and will also strengthen the scientific value of studies in fluid physics.

The centrifuge is also the only method currently available to create fractional gravity fields. Fractional gravity allows scientists to develop models to explain the processes that lead to changes observed during spaceflight. It remains the only approach to develop the predictive theories to explain how gravity may have an impact living and physical system.

Without the centrifuge, much of the science that is completed on ISS will be of diminished value

ESA Report

EUROPEAN SPACE AGENCY

ESA offers the following responses to three questions posed by NASA's ReMAP Task Force with regard to research on the ISS in terms of both its national and scientific importance. The questions being addressed by ESA are:

1. Justification for doing research on ISS: why is the ISS necessary for your agency's research?
2. What research requires a short-term mission and what research necessitates a long-term mission in space?
3. What are the research areas in which use of the Centrifuge on ISS is important for your agency?

Concerning the first of these questions Eighteen years ago Europe was invited amongst other Partners to participate in the joint development and exploitation of the Space Station for the pursuit of both fundamental and applied research. Since that time ESA has committed not only a significant financial engagement to develop key infrastructure elements of ISS but also in a close dialogue with NASA and other Partners for its coordinated utilization. In view of these investments ISS is the centerpiece for Europe for research in life and physical sciences in microgravity.

In answer to the second question I would like to emphasize that we do not see short and long-term missions as being separately linked to specific research areas. Clearly the effects of long-term exposure of humans to low-gravity and radiation conditions can only be researched using space stations. In the other areas such as fluid physics, biotechnology, crystal growth, cell biology, combustion etc. it is true that individual experiment runs can be relatively short (hours, days) but the days of one-off experiments research are long gone. Nowadays ESA receives proposals that are for programmes of research involving extensive iteration of parameter variations extending over weeks and months. Sounding Rocket activities are essentially for pre-cursor experiments and cannot off-load short duration experiments from ISS. Russian Foton missions offer some research possibilities but are extremely limited on real time data interaction and offer only limited interactive capability. In this connection SPACEHAB flights can offer interesting near term possibilities and ESA has been extensively involved in recent SPACEHAB missions. ESA would therefore like to suggest to the Committee that NASA be urged to consider continuing SPACEHAB research missions during the ISS assembly period.

For the last question, ESA presently develops facilities such as EMCS and BIOLAB that have their own built-in centrifuges. These facilities are directed at research in biology and small plant physiology and require only centrifuges of moderate size. ESA presently studies a mice facility that will also have a 90 cm. Centrifuge adequate for research on mice. So, up to now the research plans of ESA do not significantly require the use of the large centrifuge on ISS.

NASDA Report

NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN

NASDA offers the following responses to NASA’s ReMAP Task Force in the areas of Life Sciences and Microgravity Sciences with regard to research and both its national and scientific importance.

(1) Life Science Area

a) Justification for doing research on ISS: why is the ISS necessary for your agency's research?

Whether the life is limited to the earth or universal is one of our fundamental questions. To learn about the life on earth, studying in extraterrestrial environment is particularly valuable and crucial. Previously unknown biological phenomena that were veiled with terrestrial environmental factors will come into view. The International Space Station (ISS) will provide a unique environment other than the earth surface for observing biological phenomena. Findings on the ISS will not only be essential for the human space activity, but also give us great insight to the principle of the life.

b) What research requires a short-term mission and what research necessitates a long-term mission in space?

Biological phenomena consist of many processes with various time scales. Some, such as nerve excitement, complete within a second while others, human senescence for example, take years. Space motion sickness shows remission in a few days, while bone loss keeps progress. Thus, the period required for biological experiments varies. The ISS meets experimental requirements

c) What are the research areas in which use of the Centrifuge on ISS is important for your agency?

Since numerous factors affect biological responses, quantitative observations must be made in comparison with control groups. Experimental group and control groups are required to differ only in a single parameter. Other parameters must be kept exactly identical. Artificial gravity generator or the Centrifuge is thus indispensable for the entire gravitational biology research. The Centrifuge is also essential to keep experimental organisms under earth-like conditions and ready to be exposed to the space environment without remaining influence of the launch.

(2) Micro Gravity Science Area

a) Justification for doing research on ISS: why is the ISS necessary for your agency's research?

Microgravity is an environmental factor, just as ultra-high vacuums, super-high temperature, super-high pressure and high-energy radiation are. These environmental factors may work positively to aid understanding of unclear phenomena, verification of theories and/or fabrication of new functional materials. They can also be expected to contribute to the acquisition of innovative knowledge when used as tools for analyzing various phenomena.

The use of microgravity itself seldom facilitates the establishment of innovative theorems. Instead, by taking advantage of the symmetry attained from the gravity-free state, we should use it for verifying conventional theories; for verifying theorems using simplified models that eliminate the complexity of ground convection-related phenomenon; for simplifying phenomena by excluding the transport factor (namely, convection); for obtaining high-precision measurements of thermophysical properties, and for improving the function and quality of materials characteristics. ISS is the best opportunity for these microgravity science research activities.

For the fundamental physics, in order to observe or realize the steady state of the quantum physics phenomena, the microgravity condition is significantly beneficial because the quantum itself become free from the gravity acceleration.

b) What research requires a short-term mission and what research necessitates a long-term mission in space?

Method (duration)	Research Area
Drop tower (<10s)	Combustion, Fluid physics (ex. bubble movement, etc), experimental technology developments, Plasma physics
Aircraft (<20s)	Combustion, experimental technology developments, Fluid physics (ex. bubble movement, two phase flow, etc),
Sounding rocket (<6min)	Combustion, solidification (alloys, composites, etc), High precise thermo-physical measurements, Fluid physics (ex. boiling, etc), Colloid physics
Space shuttle (< 2weeks)	Diffusion (self diffusion, inter diffusion), solidification (alloys, etc), High precise thermo-physical measurements, Fluid physics (ex. Marangoni convection, etc), Composites, Crystal growth mechanism, Crystal growth from melt (semi-conductor), protein crystal growth
ISS	Crystal growth from melts and solution (semi-conductor, protein, etc.), solidification (alloys, composites, etc.), High precise thermo-physical measurements, Diffusion (self diffusion, inter diffusion), Fluid physics (ex. Marangoni convection, etc), Fundamental Physics (laser cooling, atomic clock, etc)

APPENDIX G: Opportunities to Improve ISS Productivity with AHST

Provided in Response to the ReMAP Request to OBPR for Strategies to Improve Productivity on ISS
May 2002

The Advanced Human Support Technology (AHST) program through its individual project elements can make a substantial contribution toward improving ISS productivity by increasing: 1) available crew time; 2) crew efficiency; and 3) crew safety. Estimates contained in this document for technology development lead-times reflect Code U efforts in the advancement of these technologies up to technology readiness level (TRL) 6. Developing these technologies to TRL 9 (operational implementation) will be the responsibility of the ISS Program. Each of the AHST projects identifies current problems on ISS, possible remedies, and benefits associated with pursuing these remedies.

The Space Human Factors Engineering (SHFE) Project can help realize increases in crew time up to 30 hours per week (for a crew of three) through improvements in procedure design, stowage design, communications effectiveness, systematic labeling, and revised computer interfaces. Table 1 provides the summary for each of the aforementioned areas to improve ISS productivity. More details about each of these problems and possible solutions can be found throughout. Table 1A provides some other areas where the SHFE project could effectively increase crew time with modest research efforts. Over a two year time period the SHFE project can develop these tools to TRL 6 for an eventual ISS application. Implementing these improvements will involve a joint effort between OBPR and the ISS Program.

The Advanced Environmental Monitoring and Controls (AEMC) Project can help in developing sensors that are portable and consume low power. Current station monitoring equipment (Major Constituent Analyzer, Volatile Organics Analyzer) has not performed reliably over extended time periods. The advantage of using AEMC generated sensors would be their low mass and power requirements. Other, indirect benefits associated with AEMC monitoring technologies include reduction in storage volume and providing for a safe environment. Table 2 outlines the areas of improvement that could be achieved through R&TD in the AEMC project. By developing these miniaturized monitoring technologies, it is estimated that there would be mass savings of more than 100 lbs for the instruments alone. Developing real-time monitoring devices (e.g. microbial monitors) can save up to 125 hours of annual crew time for microbiological monitoring and also would reduce expendables.

The Advanced Life Support (ALS) Project has engaged in research and technology development activities with the goal of validating ALS technologies in an integrated test environment. The focus of the ALS Project on the development of next generation technologies includes development of technology upgrades for ISS. Table 3 outlines the mass and crew-time savings that would be achieved through the activities in the ALS Project. It is estimated that developing resource recovery technologies can save upmass to station by 3000-4000 lbs annually. Some other proposed upgrades can improve the power efficiency of currently baselined ISS technologies. Most of these savings can be achieved by developing unit processors for recovering resources through the air, water and solid waste streams. These processes achieve their greatest economy at crew size of seven.

The Advanced Extravehicular Activity (AEVA) Project can also provide improvement in efficiencies toward the current ISS baseline. Some of these improvements would be contingent upon cooperation with our international partners and the ISS Program. Table 4 outlines the AEVA project contributions that can be adapted to improve EVA technologies and crew time efficiency. It is estimated that by making upgrades to current EVA equipment up to 28 crew hours can be saved per EVA (assuming one EVA every other week).

As requested by the ReMAP committee, the AHST Program has made conservative estimates with regard to the crew time savings (these numbers are within a factor of two).

Table 1. Top Space Human Factors Opportunities to Improve ISS Productivity

Item	**Problem**	Remedy	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week saved**
Procedure design	Procedures are too long and complex, time wasted, errors.	Guidelines and tools for procedure writers.	Reduced crew time and errors from better procedures.	Guidelines, prototypes, training material.	2	6
Stowage design	Ineffective, blocks access, crew time spent rearranging for access and searching for items.	Novel designs for stowage design and use of space.	Reduced time repeatedly rearranging stowed inventory.	Design concepts developed and tested.	1.5	3
Communications Effectiveness	Audio Terminal Units (ATU) located at far ends of US modules, noisy environment, time spent translating to ATUs and other crew members to communicate.	Provide portable communications units; untethered (wireless) comm.	Improve communications effectiveness, reduce time spent translating to comm hardware and other crew members.	Modify off the shelf portable communications options.	2	9
Systematic Labeling	Inconsistent or not meaningful, not user centered.	Systematize labeling.	Reduced time and errors.	Develop standard requirements and processes for labeling.	1	3
Revised Computer Interfaces: - navigation - log in & passwords - C&W	Lack of commonality; Cumbersome too many IDs, passwords too many pages to resolve warnings	Revise interfaces for greater commonality among systems, payloads, Caution and Warning (C&W).	Reduced time and errors; reduced time to access / control systems.	standardize navigation 1 ID & password per crew member reorganize displays for consistency	3	9

Notes:

1. The details of crew hours saved per week are explained in the pages following Table 1A.
2. For sanity checks on the time savings estimate, the following ISS Operations experts were consulted:
   - ISS Mission Integration and Operations Office representative to crew time tiger team.
   - Biomedical Engineer (from mission control center back room; supports flight surgeons).
   - Crew trainer from Mission Operations Directorate.
   - Astronaut who was heavily involved in Expedition 3 ground support.
   - Representative from ISS independent assessment group.

Table 1A. Additional Space Human Factors Opportunities to Improve ISS Productivity

Issue	Problem	Remedy
Inventory Management System (IMS)	Excessive crew time to locate items.	Redesign IMS.
Automation	Many crew tasks do not require human judgment.	Identify tasks with highest benefit to cost ratio.
Flight Crew Equipment	Many crew equipment items were not designed with serious attention to usability because they were not critical items.	Redesign items such as vacuum cleaner (does not retain debris when opened), fasteners (used many, many times per week), etc. to save crew time.
Communication with Various Systems	Inefficient and inconsistent communications with systems.	Standardize interfaces to e.g. IMS, other devices, by using PDAs.
Scheduling Tools	Crew time inefficiencies may occur because scheduling tools may not address resource requirements and conflicts (e.g., some tool or location needed by two different activities; assistance from 2nd crew member needed briefly during procedure).	Implement analysis/simulation tools with necessary sophistication to anticipate conflicting requirements of various tasks being scheduled for different crewmembers.

OPPORTUNITY: Procedure Design Improvements

CURRENT TIME COST:
8 hours/week PER CREWMEMBER

- Procedures are long and are not clear; reading them takes time, especially if they are unclear.
- Assume procedures are used primarily during work hours (6.5 hours/day).
- Assume procedures are used primarily during the work week (5 days).
- Assume 1/2 of work performed during work hours (6.5) is new, complicated, or infrequent, and therefore procedures are used 3.25 hours/day.
- Assume procedures are cumulatively 1/2 of the total task time (1.63 hours/day, 8.13 hours/week).
- Since all crew members use procedures, assume this time is per crewmember.

POSSIBLE TIME SAVINGS

2 hours/week PER CREWMEMBER

- Procedure approach, content, and technologies are all candidates for human factors review and improvements. Changes in accordance with human perceptual or cognitive capabilities and established Human Factors (HF) guidelines and methodologies will result in instructions that are more readily and quickly comprehended.
- Assume that HF improvements in procedures could reduce time costs associated with them by 25%. This would save 0.4 hours/day and 2 hours/week.

NOTE:

- Crew may be inclined to skip procedures entirely because they are long and not clear; skipping procedures results in increased possibility of errors. HF improvements to procedures will improve accuracy of performing tasks because: (1) information will be clearer, and (2) procedures will not be skipped.
- Impact from reading procedures is a larger issue for Russians reading US procedures written in English.
- Procedures are more of an impact for first-time, difficult, or infrequent operations.
- There may be a learning curve associated with procedures.

OPPORTUNITY: Stowage Design Improvements

CURRENT TIME COST: 5 hours/week PER CREWMEMBER

- Lack of enough dedicated stowage volume/lockers requires crew to stow cargo in open volume, in front of workstations, equipment, maintenance panels, or stowage panels; crew repeatedly rearranges stowage to perform daily activities.
- Assume this impact occurs on workdays, as well as on non-work days when crew does housekeeping and recreation (7 days/week).
- To gain access to other equipment, assume crew spends 0.75 hours/day, 5.25 hours/week.
- Since all crewmembers interact with stowage, assume this time is per crewmember.

POSSIBLE TIME SAVINGS

1 hours/week PER CREWMEMBER

- Additional and more organized stowage accommodations facilitated by innovative design solutions would reduce need to move things out of the way for access.
- Time spent looking for items can be reduced if stowage facilities provide means of quickly identifying contents.
- Assume reduce time demand by 25% and save 0.2 hours/day, 1.4 hours/week.

NOTES:

- Crew repeatedly rearranges stowage to consolidate; even with stowage system improvements, the crew will still have to stage for transfers and would occasionally rearrange inventory for efficiency.

OPPORTUNITY: Communications Effectiveness Improvements

CURRENT TIME COST:
6 hours/week PER CREWMEMBER

- Communications with each other is impacted due to acoustics. It takes time to translate to each other or to Audio Terminal Units (ATUs), which are located the ends of modules. Assume 0.5 hour/day spent translating to each other and to ATU to communicate, primarily on work days (5 days/week). This costs 2.5 hrs/week.
- Communication with ground – takes time to translate to ATU to talk – takes time away from other tasks (ref. robotics on exp 4 interrupted several times to talk to ground). Assume 0.5 hour/day translating to ATU to address ground calls. This is primarily on work days, and costs another 2.5 hours/week.
- Assume 4% increase in communications time due to interruptions and acoustic noise interference. With 6.5 work hours/day, this costs 0.26 hour/day or 1.3 hours/week.
- Summing the three sources of time costs from communications problems results in 1.26 hours/day, or 6.3 hours/week.
- Since all crew members must communicate with each other and the ground, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

3 hours/week PER CREWMEMBER

- Portable communication could reduce costs associated with communication issues by 50% and save approximately 0.63 hours/day, 3.15 hours/week

OPPORTUNITY: Systematic Labeling Improvements

CURRENT TIME COST:
3 hours/week PER CREWMEMBER

- Some hardware is not labeled, is labeled unclearly, or does not match procedures or other documentation. Time costs are associated with delays from trying to identify equipment. The crew sometimes re-labels items themselves on-orbit, which also takes time.
- Assume time impact from labeling problems is 7 days/week.
- Assume labels are the largest impact during daily ops, work hours, and meal prep (activities which total 12.5 hours per day).
- Assume 3% increase in task time due to labeling issues. Applied to 12.5 hours per day, the labeling impact is 0.4 hours/day, or 2.6 hours/week.
- Since all crew members interact with labels, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

1 hours/week PER CREWMEMBER

- More complete labeling and better commonality with procedures might result in 50% saving: 0.2 hours/day and 1.3 hours/week.

OPPORTUNITY: Revised Computer Interfaces Improvements

CURRENT TIME COST:
13 hours/week PER CREWMEMBER

- Software displays on computers have been reported to have basic human factors flaws (appearing like a familiar Windows application but not behaving like that application).
- Displays have been reported to be difficult and time-consuming to navigate across screens.
- Crews report too many usernames and passwords to remember.
- Displays are reportedly dissimilar enough from other displays on-board to cause confusion and transfer-of-training issues.
- Assume the largest impact from displays is on work days (5 days/week).
- Assume the largest impact is during work hours (6.5), planning & coordination (0.5), and daily systems ops (1.5) totaling to 8.5 hours of work involving displays per day.
- Assume 30% of task time due to Human Computer Interface (HCI) issues. With 8.5 hours of task time involving displays, the impact is 2.5 hours/day, or 12.8 hours/week.
- Since all crew members interact with computer interfaces, assume this time is per crewmember.

POSSIBLE TIME SAVINGS:

3 hours/week PER CREWMEMBER

- Focused human factors and usability evaluations of interfaces as well as development of more useful and generalized standards should improve the usability of the displays and reduce the time spent interacting with them by 25%: 0.6 hours/day, or 3.2 hours/week.

Table 2. Top Advanced Environmental Monitoring and Control Opportunities to Improve ISS Productivity

Item	Problem	Remedy	Benefit	Mechanism	Time frame	Savings	Safety
Enose	Air quality on ISS must be monitored for trace contaminants. Existing space-qualified analytical instruments, MCA, VOA, TGA, are larger, costlier, and complex. MCA, VOA, and TGA have all had problems (though some success as well).	Develop simpler, yet highly capable Enose technology. Less sensitive than analytical device like VOA, but more robust, virtually no maintenance. NASA Enose is designed to be quantitative and future units will have improved classification capability.	More air quality checks through use of numerous small deployable, possibly handheld units. These units serve as a first alert to chemical hazard, and as some backup function to the primary analytical air analysis instruments. The unit will be crew-upgradeable by changeout of the polymer chip and software upgrades.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	2 yrs to build and test 2nd generation prototype.		Enhanced safety through better understanding of chemical environment.
Tunable Diode Laser (TDL) Gas Sensor	(1) VOA or any other highly capable analytical instrument can nevertheless not detect every species of interest. (2) Miniature, sensitive, specific devices will be useful throughout the life support system, to indicate system health.	TDL gas sensor is very sensitive and specific. In the near term, Difference Frequency Generation (DFG) has been successfully used to detect formaldehyde levels. In the longer term, non DFG TDL development for smaller, more rugged, and efficient units.	Monitoring of chemicals that are beyond the capability of current analytical instrument. Small size and power make monitoring of many sites feasible.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	2 yrs for DFG version or 5 years for direct TDL.		Enhanced safety through better understanding of chemical environment.

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time frame**	**Savings**	**Safety**
UV/Raman Bacterial Sensor	Rapid microbial testing can reduce the water storage requirement (currently two days).	Develop rapid test for microbial analysis. Leverage related efforts in astrobiology, planetary protection, and counter-terrorism using UV/Raman spectroscopy	Saves required storage mass of water and associated tankage.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.		23 kg water/person/day plus associated tankage no longer need be kept on board. Savings of crew time since UV/Raman will be less labor-intensive than plate culturing.	Will be as effective as plate cultures, but take less time.
Microgravity Reagentless Organic Acid and Alcohol Detection in Water	Total organic carbon analysis of water does not discriminate between toxic and non-toxic organics, thus the TOC limit is very strict.	Organic carbon analysis that will discriminate for alcohols or acids thus allowing for a safer determination of potable water quality.	Assessment of water quality while being much less demanding of the TOC requirement resulting in better assessment of water safety.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	Ready for ground test in months.		Improved safety through improved water quality analysis.
Colorimetric Solid Phase Extraction for Biocide Determination	Trace biocide in potable water has been identified as a potential problem in ground testbeds. Iodine can potentially impair thyroid function; algyria of the skin can occur due to excessive silver.	These are a set of rapid, simple, specific tests for biocides which to date have been tested in KC135 flights.	Improved safety through identification of safe biocide levels in potable water.	AEMC PI has been coordinating with ISS operations since the start of the NRA grant.	<2 years		Improved safety through verification of safe biocide levels.

Item	Problem	Remedy	Benefit	Mechanism	Time frame	Savings	Safety
DNA Microchip-based Microbial Monitoring	Level of pathogenic organisms in the spacecraft environment and growth of biofilms in water supply lines.	DNA microchip approaches can be used to identify the microorganisms.	Improved safety through the identification of safe levels of microorganisms.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	4-6 years		Improved safety through verification of safe microbial levels.
Miniaturized Gas Chromatograph Mass Spectrometer (GCMS)	Monitoring of air and water to assure safe levels of trace chemicals and microbials as well as proper operation of life support equipment through monitoring of process gases. If all these can be monitored effectively with a single instrument, mass savings of multiple instruments is obtained.	This approach employs GCMS, which is the "gold standard" for ground-based analysis, in a small, low power, highly capable instrument.	Improved safety through speedy identification of safe levels of trace chemicals, analysis of major constituents and unknowns, and microbial analysis for either air or water samples.	AEMC works with ISS operations, ALS, and MSFC on prototype testing and implementation plan.	3-5 years	Mass savings over multiple instruments, roughly 40 kg.	Improved safety through verification of safe chemical and microbial levels; and proper operation of life support equipment.

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time frame**	**Savings**	**Safety**
Lack of Near Real-time Microbial Monitoring	Present methods are minimal at best and in addition are crew time intensive, do not identify genus/species at any level, and require 2 to 5 days to obtain results.	Automated microbial monitor that can provide near real-time assessment of harmful microorganisms in the environment.	Sample analysis within 2-5 hours, reduction in crew time, does not rely upon culturing microorganisms in flight (eliminates potential biohazard). Provides identification.	Resources to develop an automated microbial monitor.	2-3 years	Estimated net annual crew time savings as follows: air = 8 h vs. present 18 h; surface = 10 h vs present 25 h; water = 8 h vs present 108 h; total = 26 h vs present 151 h; total net annual savings = 125 h. Time to obtain results reduced from 5 days to < 5 h/sample. Logistics savings cannot yet be quantified.	Improved capabilities for portable water quality monitoring

Table 3. Top Advanced Life Support Opportunities to Improve ISS Productivity

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time-frame**	Savings
Sabatier reactor	CO_2 currently vented from ISS; O_2 lost must be replaced by splitting H_2O resulting in net H_2O loss from ISS systems.	Utilize CO_2 via Sabatier reactor to produce water for splitting to O_2.	Saves upmass of resupplied water ~ 2000 lbs/year (w/ 7person crew).	ALS works with MSFC to develop upgrade for ISS ECLS System	<2yrs	2000 lbs upmass/year
Advanced catalyst substrate, reactor/heater design for retrofit into the ISS TCCS catalytic oxidizer.	Trace Contaminant Control System (TCCS) on ISS is a catalytic oxidizer - charcoal combination. The current Oxygen Regeneration Unit (ORU) weighs 35 lbs.	This advancement combines the heater and catalyst into a single package which is more energy efficient and would be a separate ORU weighing 5-10 lbs instead of the current ORU of 35 lbs.	Mass savings & reduced energy consumption.	MSFC SBIR and NRA efforts - the initial design that runs on 27 VDC power is at TRL 6. Now being tested under MSFC CDDF funding - will be at TRL 6 by the end of this FY.	2-3 yrs	Upmass savings is modest at 30 lbs with ORU replacement every 5 years. Reduced energy consumption of 20% (122 watts vs 98 watts).
Advanced food packaging.	Conventional packaging is higher mass.	Nanomaterials for food packaging.	Could result in up to 50% less weight in packaging with the same or better water & oxygen barrier properties.	Triton Systems is in the first year of the SBIR.	3-5 yrs	750 lbs/year
Solid waste de-watering.	Currently all wet trash is thrown away; wet trash is bagged, then crew wraps bags with tape to reduce smell and then trash is stored on-orbit until burned up in Progress or returned on Shuttle.	Extract and recycle water from trash.	Saves on water transfer requirements; save crew time spent on packing wastes/trash; saves on storage volume.	Current low TRL lyophilization NRA at ARC near completion; no other on-going work in this area.	3-5 yrs	280 - 675 lbs/year

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time-frame**	Savings
Bacteria Filter Pressure Drop Sensing	Bacteria Filter Element (BFE) service life presently set at 1 year based on ground evaluation and analysis. Replacement is based on time on stream rather than actual filter loading to the upper pressure drop threshold of 0.5 inches of water.	Develop flow measurement technique correlated to BFE pressure drop to determine replacement need rather than time on stream.	Saves crew time, up/down mass, stowage volume, and may eliminate the potential need to purchase additional spare elements. Note that there are a total of 88 BFE spares as of October 2000. At least 10 of those spares have been replaced. Using the 1-year replacement interval, new spare elements will need to be purchased within 7 years. Extending the service life by only 6 months extends that to 10 years.	Develop flow measurement technique correlated to filter loading and pressure drop or a more direct pressure drop measurement technique.	2-3 years	0.09 m^3/year (3.1 ft^3/year) by doubling present service life. Doubling service life avoids future spares purchase of at least 48 BFE units at a ROM of $5,000 each for ground use only. Flight qualification may double the unit price. Annual mass savings is 17 kg by doubling service life (based on 2.62 kg BFE weight and 13 presently on orbit).
Lack of a Portable Emergency Response Air Scrubber.	The present approach (LiOH and charcoal canisters) provides a maximum 9 cfm flow making scrubbing duration and recovery time very long in emergency situations. Scrubbing system requires significant stowage volume.	Develop a high flow, dedicated emergency scrubber that can be used to recover from fire, particulate matter, and chemical release events. Such a scrubber will help to preserve expendable ECLSS resources.	Reduced recovery time from an emergency event.	Leverage ALS and SBIR technologies on ultrafiltration and trace contaminant control into the development of a portable emergency response-scrubbing unit.	2-3 years.	51.7 kg upmass/event. Assumes complete contamination control system overhaul. Stowage volume is most likely an even trade.

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Time-frame**	Savings
Polar Volatile Organic Compound (VOC) Impacts on Water Processing System Performance and Logistics	Water processing systems on ISS are more sensitive to polar VOC concentrations in the cabin than the crew by an order of magnitude. Impact is increased water processor logistics and crew time to maintain proper function.	Evaluate alternate cleaning agents for use onboard-crewed spacecraft that are compatible with equipment, water processor function, and provide adequate cleaning function. Further investigate the cabin atmosphere/humidity condensate trace contaminant partitioning to better assess the problem.	Reduced water processor logistics mass and crew time.	Fund evaluation of alternate cleaning solvents. Fund experimental testing to expand the knowledge base on contaminant loading of humidity condensate.	1-2 years.	Estimated 45 kg/year savings on expendable beds.

* These are the costs associated with developing these technologies to a TRL 6.

Table 4. Top Advanced Extravehicular Activity Opportunities to Improve ISS Productivity

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
External Science Automation	US and Russian external science experiments are consuming valuable crew time for installation and removal support.	Design all external materials exposure experiments for robotic installation and removal. Discontinue all totally manual experiments. Rely on automated external pallets. Reserve EVA support for off-nominal failure response to science success.	EVA time reduced and made available for other IVA science. Using Mir history as an example, total EVA demand would be reduced by 26% or 100hrs thru assembly complete	International management decision	0	2
Single EVA Suit	Maintaining and using both Orlan and EMU suits adds to crew overhead demands. Orlan does not have regenerable CO_2 removal or rechargeable battery, as does the EMU. Higher Orlan pressure minimizes prebreathe demand for crew time and O_2 waste/resupply (no overnight campout, no mask prebreathe, short in-suit prebreathe).	Select a single suit type. Discontinue production and maintenance of the other suit type. For the widest range of crew size accommodation, most mobility/dexterity and least burden upon resupply consumables, the EMU would be the preferred choice. The single size minimal prebreathe Orlan could be selected if improved gloves and task lighting were implemented and a smaller range of crew sizes could be used.	Reduced logistics mass and stowage volume. Less crew time demanded pre-flight and onboard to obtain and maintain dual suit proficiency.	International management decision required. Common interface for EMU gloves on Orlan suit required. Better helmet mounted lighting needed to allow work to continue during orbital darkness.	1	3

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Single EVA Airlock	The joint airlock can accommodate both Orlan and EMU suits. Its central location and pump, which recycles depressurization gas, make it ideal for common use. Continued use of the Russian airlocks wastes limited O_2/N_2 gases.	Discontinue use of the Russian airlocks, which have no atmosphere-recycling pump.	Reduced resupply of ISS O_2 and N_2 gases. No crew time needed for gas tank changeout or other EVA preps. Progress, Shuttle and DC1 stowage mass/volume freed for other needs.	International management decision required. Access to Russian segment from joint airlock would be improved by Strela crane mounted on joint airlock by new interface adapter.	1	1.5
Water Tanks	Water must be manually transferred from the Orbiter to ISS during docked operations. The transfer time and ISS stowage volume detract from other users. Time to refill EMU water tanks is also a burden.	Replace the current suit cooling system sublimator with a radiator.	No crew time or stowage wasted on EVA cooling water management.	Replace the life support sublimator with a freezable radiator. Finish development of existing radiator design.	2	1
CO_2 Removal Canister	Both LiOH and Metox CO_2 removal canisters place demands upon crew time and stowage. Removal, installation, and regeneration activities detract from higher priority scientific tasks. Shuttle and ISS logistics are burdened unnecessarily.	Replace the existing CO_2 removal system (canisters and regenerator oven) with long life, self regenerable system. Consider swing bed or membrane systems.	No crew time or STS/ISS stowage wasted on CO_2 system logistics.	Replace existing CO_2 removal system. Develop 2-3 candidate solutions to ensure effective solution.	3	2

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Communications Cap	Donning, doffing, and manifesting of the EVA "Snoopy" comm cap wastes crew time and stowage mass/volume.	Replace the comm cap with a microphones and speakers permanently installed in the suit's helmet or upper torso.	No crew time or stowage wasted on comm cap operations.	Modify existing suit electronics. Include noise canceling features to offset audible airflow interference.	2	1
Helmet Antifog	Helmet insulation and airflow is not sufficient to preclude visor fogging from breath moisture. Manual application of soap solution wastes crew time and has caused eye irritation when excess inadequately removed.	Devise permanent antifog coating and/or modify existing helmet so inner and outer visor sealed for improved insulation.	No crew time wasted on manual application and removal of antifog solution.	Modify existing helmet coatings and insulation.	3	1
EVA Bioinstrumentation	Crew time wasted on installation, removal, and cleanup of EVA bioinstrumentation wire harness and sensors.	Devise wireless sensors permanently integrated into the suit upper torso or undergarments.	No pre or post EVA time wasted on biomedical instrumentation.	Replace current biomedical sensor system.	2	1
Drink Bag	Resupply of reusable or disposable drink bags occupies limited manifest mass/volume. Filling and degassing procedures waste crew time.	Eliminate the drink bag. Replace with increased capacity life support water tanks. Tap into cooling water supply for drinkable water.	No pre or post EVA time wasted on drink bag operations. No manifest.	Modify existing suit water system.	2	1

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
EVA Information Display	EVA crew must rely on preflight and on-orbit training to memorize external task procedures. Paper cuff checklist is too full to accommodate any ISS task data. IVA crew burdened by serving as procedures support service. Extended increment duration negates utility of pre-flight training.	Develop arm or helmet mounted display.	On-board and pre-flight crew training time can be reduced.	Prove cutting edge commercially produced displays are compatible with suit external or internal environments. For arm mounted display, provide power via existing external battery/harness. Consider both pre-EVA memory loading and radio linked interactive data.	2.5	2
Onboard Virtual Reality Training Computer	EVA crew must rely on preflight and on-orbit training to memorize external task procedures/techniques. Ground based VR simulation is not available on-orbit. In cabin suited and unsuited practice of external tasks detracts from IVA science time. IVA crew burdened by serving as procedures support service. Extended increment duration negates utility of pre-flight training.	Develop small, lightweight, low power and portable virtual reality capability. Use for crew self paced on-orbit instruction and refresh training. Devise means to link and display software during EVA as in-situ task procedures aid.	On-board and pre-flight crew training time can be reduced.	Condense ground based hardware and software to be on-orbit compatible. Devise radio link using existing ISS transceivers and antennas to access software/simulation during EVA. If radio link is impractical, consider sufficient memory on suit for expected tasks.	3	2
Robotics Control Location	IVA crew time for science is reduced by time spent operating external robotics.	Demonstrate capability for ground team to safely and productively conduct all SSRMS and SPDM operations.	No IVA crew time needed to support EVA tasks.	Develop and demonstrate automated safety functions and compensation for time delay issues.	3	5

Item	**Problem**	**Remedy**	**Benefit**	**Mechanism**	**Yrs to TRL 6**	**Total crew hours per week/EVA saved***
Robotic Assistant	Productive EVA time is unnecessarily expended on low complexity overhead tasks. $^{1}/_{3}$ of external crew time is spent relocating and reconfiguring body restraints and tools. More time is wasted on hardware inspections and post task closeout photography.	Provide dexterous robotics that can perform simple EVA tasks such as worksite inspection/photography and manipulation and transport of EVA crew tools/restraints. Maximize usage and capabilities of planned dexterous robotics (SPDM).	$^{1}/_{3}$ of total EVA for ISS assembly, maintenance, and science would be eliminated. This could equate to over 100 hours thru assembly complete.	Complete development of Robonaut. Enhance capabilities and usage of SPDM robotics.	3	3
Voice-activated EVA Crew Control of Robotic Manipulator	The EVA crew has no capability to command robotic manipulator motions directly. IVA and EVA crew time is wasted on this interface deficiency.	Create the ability for direct voice command control of external robotics.	Crew transported on the end of the manipulator or guiding manipulator attached cargo can keep hands free for work and rapidly maneuver into needed work positions.	Integrate voice recognition/command software into suit and robotic systems. Use existing radios for communication transmissions. Develop automated manipulator joint trajectory and contact analysis.	2	0.5
IVA Monitor	Using the IVA crewmember to read procedures, operate cameras and track EVA crew tasks detracts from IVA science ops.	Use Russian proven technique which relies upon MCC based EVA expert to provide procedural advice and track external crew tasks.	One crewmember freed for over 6 hours during each EVA.	Management decision.	0	2

* Average of one EVA every other week assumed.

APPENDIX H: OBPR Science Metrics Presentation

Research Maximization and Prioritization Task Force

Office of Biological and Physical Research Science Productivity Metrics

Background
Current Approach and Status
Future Directions

Michael J. Wargo, ScD
Deputy Director, and
Enterprise Scientist for
Materials Science
Physical Sciences Division

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Science Productivity Metrics: Background

Metrics for Basic Research: Requirements, Findings and Recommendations

- We have been committed to establishing, growing, and improving a high quality scientific research program
  - "It's the right thing to do."
  - We have had a series of independent reviews by NAS, NAE, IOM, NMAB, etc.: "Measure by Review"
  - OBPR Task and Bibliography
- Government Performance and Results Act, 1993
- *Implementing The Government Performance and Results Act for Research, A Status Report, 2001*
  - National Academy of Science
  - National Academy of Engineering
  - Institute of Medicine

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Government Performance and Results Act, 1993

- Law as interpreted by Office of Management and Budget Circular Requires:
  - NASA Strategic plan (at least every three years)
  - NASA Annual Performance Plans
    - Accompany budget
    - Establish Annual performance goals and targets
    - “outcome” orientation, quantitative, fiscal year specific targets
    - Must align with strategic plan
  - NASA Annual Performance Reports against past year’s plan
    - NASA has instituted annual review by NASA Advisory Committee
- NASA has not been satisfied with the different approaches used to date. We are working with the Office of Science and Technology Policy and the Office of Management and Budget to apply NRC guidance to develop an appropriate approach for research programs.

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Science Productivity Metrics: The Problem of Measuring Science Outcomes

Reference: *Implementing The Government Performance and Results Act for Research, A Status Report* NRC, 2001

- “Because the outcomes of most research programs are not clear for several years, especially those requiring launching, the effort to report outcomes can lead to the use of numbers that mean little with respect to the new knowledge hoped for.” p. 104
- “The struggle is to quantify ‘intangible’ results, such as knowledge. Most government programs have a product that is easy to describe, including many NASA missions. But when knowledge is the objective, its form is unknown, and its discovery is often serendipitous. That kind of objective defies the use of conventional metrics.” p. 105

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Science Productivity Metrics: Proposed Best Practices

How do we capture information appropriate to assess science quality and productivity?

OBPR Program Tasks and Bibliography, FY2001 now includes fields intended to reflect the impact and utility of the research results:

- Impact on America: This section has been added so that we can better understand the impact that NASA funded microgravity research has on America.
  - Industry Affiliates
  - Innovative Technologies Developed: If this investigation has contributed to the development of any new technological advances, please identify each one and include a short description.
  - Who is using the results of your research?
  - Where have your recent graduate students found employment?
  - Number of times that your work has appeared in the popular press?
  - Number of times that your work has appeared on a magazine cover?
  - If you have a science website, or your work is represented on one, please include the address.

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Science Productivity Metrics: Proposed Best Practices

How do we manage science to help ensure research productivity?

- Peer review of ground-based and flight research via the NASA Research Announcement process
  - Proposals seeking renewal must include a section describing progress in the prior funding period.
  - The peer review panel is required to include as part of their review an assessment on the qualifications of the Principal Investigator, Co-investigators, and institutional capabilities.
- Continued assessment of flight investigations during development
  - Criteria for experiment success are established and reviewed
    - Example: Science Requirements Document - criteria defined for:
      - » Fully Successful
      - » Successful
      - » Minimally Successful
  - The need for access to space to accomplish the scientific objectives continues to be assessed. Has progress been made on the ground that mitigates the need for the flight experiment?

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Current Metrics: FY2001 Bioastronautics Research Division Task Summary

Total Number of Research Tasks	312
Total Number of Principal Investigators	260
Total Number of co-Investigators	357
Total Number of Students Supported	877
Post-Doctorate	206
PhD	167
Graduate	195
Undergraduate	309
Total Number of Bibliographic Listings	929
Articles in Peer-Reviewed Journals	266
Books / Chapters in Books	26
Dissertations and Theses	24
Patents	5
Other (proceedings, non-peer reviewed articles, etc.)	608

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Current Metrics: FY2001 Fundamental Space Biology Division Task Summary

Total Number of Research Tasks	149
Total Number of Principal Investigators	122
Total Number of co-Investigators	105
Total Number of Students Supported	563
Post-Doctorate	146
PhD	111
Graduate	83
Undergraduate	223
Total Number of Bibliographic Listings	576
Articles in Peer-Reviewed Journals	233
Books / Chapters in Books	13
Dissertations and Theses	10
Patents	2
Other (proceedings, non-peer reviewed articles, etc.)	318

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Current Metrics: FY2001 Physical Sciences Division Task Summary

Total Number of Research Tasks	553
Total Number of Principal Investigators	451
Total Number of co-Investigators	719
Total Number of Students Supported	1407
Post-Doctorate	186
PhD	527
Graduate	311
Undergraduate	383
Total Number of Bibliographic Listings	2020
Articles in Peer-Reviewed Journals	669
Books / Chapters in Books	43
Dissertations and Theses	29
Patents	15
Other (proceedings, non-peer reviewed articles, etc.)	1264

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New Metrics Under Consideration by OBPR

Metrics related to or based on Committee on Microgravity Research (CMGR) Analysis of Physical Sciences Division Program

- Quality of Investigators (Is the program capable of attracting a cadre of high quality investigators?)
  - Nobel Laureates
  - Membership in Academies
  - Fellows in Major Scientific Societies
  - Awards
- Quality of Research
  - Publication in respected journals
  - Citation index
  - Download of flight data for use by other scientists
- Impact
  - Documented Industrial Impact
  - Textbooks
  - Patents

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New Metrics Under Consideration by OBPR

Metrics related to or based on ReMAP research prioritization criteria

- Scientific Importance
- Impact on Scientific and Technological Community
- Relevance to a Broad Constituency
- Contributions to National Goals

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New Method for Determining Metrics Based on NRC Study

- Plan for Expert Review (Measurement by Review) p. 105
  - Continue to report GPRA type metrics
  - Review one-third of the research program annually
    - Provides regular scrutiny
  - Review of the degree of integration within research and the connection of the research to applications and technology
  - “Originators of this approach believe that the research community will show far more enthusiasm for evaluating research programs with expert review than for evaluation according to annual measures and results.”
- Relieves several major concerns about the past method.
  - When the importance and relevance of a program are defined in terms of metrics, a program considered unmeasurable or difficult to measure could lose priority in the budget process relative to programs that are easier to quantify.
  - Unmeasurable or difficult-to-measure programs give the perception that their progress and ability to produce useful results are not being tracked regularly.

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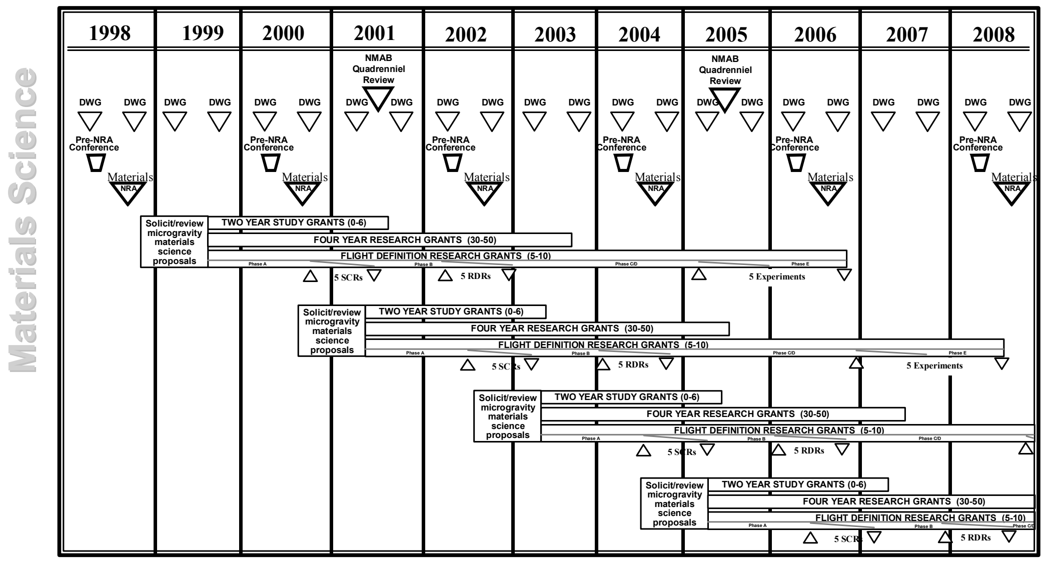
Microgravity Research Performance Goals

Implementation Plan to Accomplish Program Objectives

Performance Goal 1.25 Use microgravity to establish and improve quantitative and predictive relationships between the structure, processing, and properties of materials.



APPENDIX I: Ethical Issues Relevant to OBPR Research and Space Flight
L. Zoloth, Ph.D.
July 27, 2002

The nature, goal and purpose of the crew.
The science on the ISS is done at this time by a human crew: simultaneously vulnerable, brave and limited by their embodiment. The ReMAP committee was confronted with this reality as a central feature of our work, and this defined many of our discussions of first priorities. One of the leading ethical issues we confronted was the seriousness of the risks that the crew faces in space.

The crew can be understood as functioning in three ways, and for each role, intrinsic rights, duties and obligations for the crew and for the surrounding community--we who send them into space on our behalf---changes.

First, they are *researchers* for the scientific projects, running the science experiments, checking on the plants and animals, recording their observations and readings of the complex phenomena, and maintaining the equipment that sustains the research. In this way, they are similar to other scientists who work in extreme earth environments, such as Antarctica or volcanoes, who do their science at the risk of serious harm, or even death. We understand that such research is in part the work of particular careers in science, undertaken voluntarily, and with the assumption that risk is a feature of such investigation.

Second, the crews are *human subjects* in what is similar to classic Phase One clinical trials on how the human body reacts to microgravity, and to long term confinement in the harsh and precarious environment of space. (We on earth are the control arm of such trials) As subjects of research, they need the full range of protects of such subjects, privacy, autonomy, and informed consent. We hope by our use of the subjects to learn better how to address both medical problems on earth, and how to address the medical problems to be solved in space for future crews. Like all Phase One trials, it is unlikely that initial research can benefit the first subjects. Like all research, it can be highly risk-laden, and can result in serious harm, so much so that NIH research commonly have Data Safety Monitoring Boards to monitor adverse incidents, harm, and death, and stop human trials if they become too dangerous. Like all such research, participation is completely voluntary.

Third, the crews are *public servants*, voluntarily undertaking a task that is difficult, highly risky and technically demanding. In this way the crew need workplace protections, similar in nature to how we protect *soldiers, police and firefighters.* Here too, persons are workers who may face the risk of serious harm or death. We assume in these cases (and the case of both NYPD and NYFD and of soldiers at war as we wrote the document) that high risk activity is a necessary component of a voluntary occupation, taken on in the name of duty, love of country and service.

Finally, they are *explorers*, privileged to take on extraordinary challenges in the name of discovery. For many on the ReMAP Task Force, this last description was the most compelling. Our ethical obligations to the crew can be mapped very differently based on how we regard the crew. Such activities have also been a classic part of all exploration, and in this, we understood the task of Lewis and Clark--part science, part military statecraft, and part commercial--as paradigmatic. Since much of the science is prioritized in order to avoid "show stoppers" (things which would terminate a mission or harm the crew). For an example, the ranking of scientific research in fire safety becomes named as a high priority for this reason.

The needs of the crew for external rescue should something go awry are the single clearest constraint on the size of the crew. A crew return vehicle only holds three persons. Much of the science proposed cannot be done with only three crewmembers. This only deepens the problem of assessing the cost/benefit analysis of good science, and the need to decide what level of risk to the crew is an acceptable level of risk. There can be no situation of zero risk--hence, what is at stake is how much risk for harm can be named as acceptable, as assessment which varies depending on how you understand the crew as scientists, subjects or soldiers. Risk level assessment drives the science priorities, for the concept of "show stoppers" became the drivers for some of the highest priorities of science. We were moved to ask: who should assess the nature of risk? How can full consent be protected? How can we clearly understand the risk as public citizens who fund and support the work? What risks are acceptable, and what unacceptable(even if the crew might wish to take them) to the larger polity?

Animal experimentation in space

International codes of law and norms of research using human subjects insist on the use of animal models for research prior to human research. In this, separate issues of the animals on board the space crafts and the station carry separate ethical challenges, an issue given great consideration by the agency. In light of the Nuremberg and Helsinki accords for research, full animal research and its facilities, and all that this implies for animal habitat and animal care, would seem to be necessitated if we intend to use humans in space. Hence, one of the priorities that was named as essential was based on this ethical norm. Animal habitats that support model organisms act as proof of principle for humans.

APPENDIX J: Glossary of OBPR Research Thrusts[8]

Bioastronautics Research Division

A. Biomedical Research & Countermeasures Program

Behavior & Performance
Research focused in six areas which include: 1) perception and cognition, 2) human physical performance, 3) personal, interpersonal and group dynamics, 4) habitability, e.g. human factors – how the person responds to the human-machine interface, 5) circadian rhythms, and 6) advance technology development in these areas.

Clinical/Operational Medicine
Research to define medical risk, test proven ground medical treatment and technologies for use in spaceflight, develop new medical preventatives or rehabilitation therapies for use by astronauts in space or on their return to Earth, and the development of advance technology for use in space for diagnosis, biomedical technical training and continuing medical education, and therapeutics.

Environmental Health
Applied research to study barophysiology, microbiology and toxicology and to develop new technologies in these areas. The purpose of this program is to better understand the specific risks, and how to prevent and treat potential health problems that occur because of the microgravity, and the confined and isolated living quarters.

Integrated Physiology
Inter-system research on the physiological and behavioral alterations that occur during spaceflight. The purpose is to define the systemic changes that occur to other organs by perturbations in another organ system, determine the mechanisms for these changes and the development of countermeasures or treatment modalities to reverse or prevent the deleterious effects associated with space flight. Examples include "how spaceflight induced physiologic responses of the vestibular system cause problems in the autonomic and cardiovascular systems" or "how changes in the digestive tract effect the maintenance of the musculoskeletal system.

Organ System Physiology
In addition to classical physiologic research, research to understand the underlying molecular, genetic, and cellular factors, and other underlying processes that result in spaceflight changes of a single organ and the development of "countermeasures" to prevent, slow or recover from maladaptive spaceflight induced changes to the specific organ. Examples include organ disciplines including cardiovascular, bone, muscle, vestibular, etc.

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[8] Alphabetical within programs

Radiation Health
Research to determine the risk and prevention of health problems induced by space radiation. Specifically research that will reduce the uncertainties associated with predicting the excess risk of carcinogenesis resulting from radiation exposure during space flight. Support ground-based research studying the biological effects of heavy ions using the NASA facility at Brookhaven for the evaluation of risk factors to radiation-induced carcinogenesis and other radiation-induced health problems. Studies will center on genetic biological research, bioengineering and radiation protection through research in radiation physics and shielding materials as appropriate and advanced technology development for the diagnosis, and prevention of radiation damage to space travelers.

B. Advanced Human Support Technology Program

Advanced Life Support
Advanced life support project conducts R&TD to provide: temperature and humidity control; atmosphere purification, and revitalization; water recovery and management; waste management; and food management. Integrated life support systems testing and validation has also been conducted by the ALS project.

Environmental Monitoring and Control and Advanced Environmental Monitoring and Control
EMC research and technology development encompasses monitoring the internal environment of a human occupied spacecraft, including the atmosphere, water supplies, and all surfaces. Monitoring implies continuous oversight of the status of these areas over time to ensure that conditions are maintained within acceptable limits and Control implies some form of feedback to the systems responsible for maintaining each parameter.

Extravehicular Activity and Advanced Extravehicular Activity
Extravehicular activity is work conducted outside the pressurized volume of a crewed space vehicle/facility. The EVA equipment consists of: the spacesuit, the primary life support system (pressurized oxygen, ventilation, and removal of CO_2, water vapor, and trace contaminants), thermal conditioning, and the tools (including robotic tools) that enable the EVA crewmember to accomplish the necessary tasks.

Space Human Factors Engineering
Human factors focuses on the role of humans in complex systems, the design of equipment and facilities for human use, and the development of environments for comfort and safety. Subject areas for human factors research include ergonomics, biomechanics, anthropometrics, workload, and performance. Design of systems and operations for human activities in space is called space human factors engineering.

Fundamental Space Biology Division

Note: All research areas focus on the effects of the space environment on the biological processes identified for each area.

Cell and Molecular Biology
Research in this area addresses how basic cellular function and properties (e.g., mechano-reception, signal transduction, gene regulation and expression, proteomics, integrin function and structure, cytoskeletal structure and function, etc.) may be directly or indirectly impacted by altered gravitational force and other space-related effects. Of particular interest are molecular and cellular studies associated with the physiological changes seen in whole animals in response to the space environment.

Developmental Biology
Research to determine the role of gravity in normal development and function, how gravity and other aspects of the space environment may affect the capacity of organisms to reproduce, and the mechanisms by which subsequent generations are affected. Of particular interest is the development of systems and structures involved in gravity sensing and response.

Evolutionary Biology
Research to understand the capacity for terrestrial organisms to evolve in the novel environment of space, and the role gravity has played in terrestrial evolution.

Gravitational Ecology
Research to understand how the space flight environment might affect the structure, function, and the evolution or stability of ecosystems, particularly as they might relate to spacecraft or planetary habitats.

Molecular Structures and Physical Interactions
Research that emphasizes the physical effects of the space flight environment, such as static boundary layer effects on gas exchange, changes in heat transfer, lack of convective fluid movements, and alterations in diffusion-limited metabolic processes, on the functioning of single-celled and multicellular organisms.

Organismal and Comparative Biology
This element elucidates the effects of chronic exposure to altered gravity and/or other space-related factors on normal physiology, metabolism, and performance of animals and plants, and compares or contrasts them among different organisms.

Physical Sciences Division

A. Fundamental Microgravity Research

Condensed Matter and Quantum Phenomena[9]
Cooperative phenomena in non-equilibrium systems; atom laser studies, low-temperature atom condensates.

Fluid Stability, Dynamics, and Rheology
Fundamental aspects of fluid behavior in low gravity, including interfacial phenomena and multiphase flows.

Fundamental Laws and Benchmark Data to Test Theories[9]
Tests of fundamental laws of physics and integrated theories requiring innovative experimental techniques. Research spans second order phase transitions in low temperature physics, relativity experiments using high accuracy atomic clocks, and fundamental aspects of materials research and combustion science.

Kinetics, Structure, and Transport Processes in Physico-Chemical Systems
Transport phenomena, kinetics, and non-equilibrium processes. Nucleation (of bubbles, soot, crystallization, etc.); rates of chemical or metabolic reactions (during combustion or cellular activity). Formation of particles such as fullerenes and soot.

Phase transformation, pattern formation, and self-assembly in physico-chemical systems[10]
Physics of processes leading to order and structure in systems of technological interest: solidification processes in metals, defect formation in crystalline materials, self-assembly in colloidal suspensions, dynamics of foams and granular systems.

Thermo physical, Physical-Chemical, and Biophysical Properties
Transport and thermodynamic data on materials and systems of technological importance.

B. Biotechnology and Applications Program

Bio-inspired and Microfluidics Technologies
Interdisciplinary research projects bringing expertise from biology, physics, chemistry, and engineering to focus on understanding the synthesis and function of macromolecular assemblies. Application to new experimental methodologies for ISS and other space-based research stressing miniaturization and automation.

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[9] Includes research targeting issues involving the physics of phase transitions.

[10] Research targeting issues in materials science; phase transformation is a well-defined and accepted nomenclature in the field of metal alloys.

Cell Science and Tissue Engineering
Applications of low-shear stress culture technology for three-dimensional mammalian cell systems; effects of mechanical stresses on cell systems. Enhancement of technology for three-dimensional tissue culture and engineering using the NASA Bioreactor as a foundation.

Energy Conversion and Chemical Processing
Combustion research on problems of energy- and environmentally-related interest.

Materials Synthesis and Processing
Reactive processes for synthesis of novel materials, including carbon nanostructures and ceramics for biomaterials applications.

Structural Biology
Micromechanics of protein crystal growth of biological macromolecules and factors controlling crystal quality; development of technologies for obtaining high-diffracting crystals of scientific interest.

C. Engineering Research Enabling Exploration

Biomolecular Systems Technology and Sensors
Integrated research projects developing technologies to monitor biological signals and processes relevant to health care, cosponsored by the NIH/NCI

Fire Safety, Spacecraft Fluid System Engineering Research
Ignition and propagation of fires in low-gravity; detection and extinguishment technologies; prediction and control of normal and cryogenic liquid behavior in vehicle systems.

Mission Resource Production and Robotic Exploration
Research on gravity-dependent phenomena inherent to technologies required for planetary exploration missions. Basic research supporting mission architecture studies and chemical process design in non-Earth environments. Examples of currently supported projects include process studies on the separation of CO_2 from the Martian atmosphere and the production of oxygen from lunar soils.

Propulsion and Power Systems
Heat transfer, thermal hydraulics, and high temperature/extreme environment materials relevant to vehicle propulsion and power technologies; microcombustion technologies for high density energy storage.

Radiation Protection
Interaction of space radiation and materials; prediction of crew radiation exposure; effective shielding strategies for crew and equipment.

Research Integration Division (Space Product Development)

A. Commercial Applied Sciences

Advanced Materials
Advanced materials research supports zeolite crystal growth for refining and chemical industries; dilute gas sensors; ceramic powders/non-oxide ceramic production; improved casting technologies and thermophysical properties research; optical fiber production for optoelectronic devices; chemical sensors, and; superconducting wires for transmission applications. This field of research benefits from the use of microgravity to alter physical properties of the materials of interest and to provide insight into previously unknown phenomena, processes, and interactions.

Agribusiness
Agribusiness explores plant research under microgravity conditions to examine plant structure absent the force of gravity. Insights gained may lead to improved agricultural products. The research also adds to the base of knowledge in the fundamental science area of plant research and contributes to other fields of knowledge, such as plant-based pharmaceutical development.

Biotechnology
The Commercial Space Centers have established substantial research collaboration with pharmaceutical firms in the field of biotechnology. Pharmaceutical CSC partners include: Amgen, Bristol Myers-Squibb, Merck, Eli Lilly, BioCryst (spinoff of a CSC), Vertex Pharmaceuticals, Abbott Labs, Upjohn, Schering Plough, and other pharmaceutical firms presently affiliated with the CSC program. This research area has proven the broadest and most successful among the three areas of commercial applied sciences in terms of market support, industry investment and near-term potential for positive economic impact.

B. Commercial Engineering Research and Technology Development

Power Generation, Storage, and Transmission
Power systems have many applications. For example, advanced solar cells, batteries and flywheels, are of interest to a wide variety of industry partners for use in electric vehicles, uninterruptible power supplies, solar electric power generators, etc.

Propulsion
Space propulsion systems include electric, chemical, hybrid, and waste gas propulsion systems. Propulsion research will enable US satellite manufacturers and providers of launch services to be more competitive in an increasingly demanding market. Advanced propulsion systems would make it possible to use smaller and cheaper transfer stages and could greatly improve spacecraft reliability and lifetime.

Remote Sensing and Autonomous Systems
Remote sensing technology, such as hyperspectral imagery, has valuable commercial and scientific applications from environmental monitoring to identifying oil and gas deposits on earth to exploring and developing extraterrestrial resources. Autonomous systems that can rendezvous and dock enable refueling, maintenance, and orbit transfers of commercial and government satellites. These systems could greatly reduce reliance on ground control, providing advantages

for scientific as well as commercial spacecraft. Greater autonomy would reduce the amount of tele-operation required in future planetary exploration.

Robotics and Structures
Robotic systems could be used in conjunction with or instead of astronauts to perform a wide variety of tasks, including inspecting, servicing, and repairing the station; manipulating and placing large objects outside the ISS, and servicing scientific experiments. Structures could improve the precision and reduce the weight of communications antennas, could lead to improved lightweight solar collectors antennas, and reflectors for low-cost robotic spacecraft, and could also reveal additional design options for ultralight spacecraft.

Telecommunications
The ERTD category addresses technology development issues of importance to commercial communications satellites, including development and testing of phased array antennas, characterization of the on-orbit radio frequency environment, demonstration of high-data-rate communications, validation of complex on-board processors accomplishing advanced signal processing tasks, testing of optical communications devices, and deployment of unique antenna structures.

Thermal Control
Thermal control consists of devices for thermal transport and storage (heat pipes, two-phase pumps, phase change materials); refrigeration subsystems (thermoelectric devices and cryogenic coolers); advanced radiators (composites); and insulation.

APPENDIX K: OBPR Research Merit Criteria

The proposed OBPR research merit criteria are as follows:

- **Scientific Importance**
  - Are the key scientific questions addressed by the specific research important?
  - Does the research represent a groundbreaking advance or is it incremental relative to the current state-of-the-art?
  - Is there a potential for insight into previously unknown phenomena, processes, or interactions?
  - Is the research a significant contribution to timely issues, or just buzzword compliant?
  - Will the research provide powerful new techniques for observing nature?
  - Will the research answer fundamental questions or stimulate theoretical understanding of fundamental processes or structures?
  - Is there potential for an important advance in knowledge or understanding in areas at the boundaries between disciplines?
  - Is this research going to help develop the future generation of scientists?

- **Impact to Broad Scientific and Technological Community**
  - Will the research have significant benefits/applications to ground-based as well as space-based operations involving the basic disciplines or cross-disciplinary interactions?
  - Will the results have broad usefulness, leading to further theoretical, experimental, or commercial and technological developments that have application beyond the particular initiative?
  - Will the research help demonstrate the benefit of using the environment of space to further the advancement of knowledge or to enhance products and services on Earth?
  - Is there a potential for stimulation of future technological “spin-offs”?
  - Will the value of the product if or when it is realized in an application be timely?
  - Will the research stimulate integration or combination of now separate concepts or information?
  - Will the research results be applicable or beneficial to an area not immediately related to the field of research?
  - What is the impact on existing international agreements?
  - Is there potential for economic impact?

- **Relevant to NASA’s Mission**
  - Will the research substantially contribute to the health, safety, and performance of humans living and working in space?
  - Will the research enhance ISS productivity?
  - Is the space environment of fundamental importance to the research, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter, or in providing access to conditions not available on Earth?
  - Will the research substantially contribute to the safety and effectiveness of robotic

  exploration missions?
  - Does the research require a NASA-unique ground-based facility or expertise?
  - Does the research advance and communicate scientific knowledge and understanding of the Earth, the solar system, or the universe?
  - Does the research expand advanced aeronautics, space science, or space technology?
  - Does this research support NASA's goal to foster the commercial use of space?

- **Contributions to National Goals**
  - Will the research contribute to national pride and to the image of the United States as a scientific and technological leader because of the magnitude of the challenge, the excitement of the endeavor, or the nature of the results?
  - Will the research contribute to education by generating student interest in science or by attracting students to science and engineering?
  - Will the research aid in the fostering of commercialization of space?
  - Will the research present opportunities for cooperation with external organizations including international partners?
  - Will the research engage and involve the public in research in space?
  - Will the research contribute to public understanding of the natural world and appreciation of the goals and achievements of science?
  - Will the research benefit the economic health of this nation?

APPENDIX L: ReMAP Prioritization Criteria and Justification

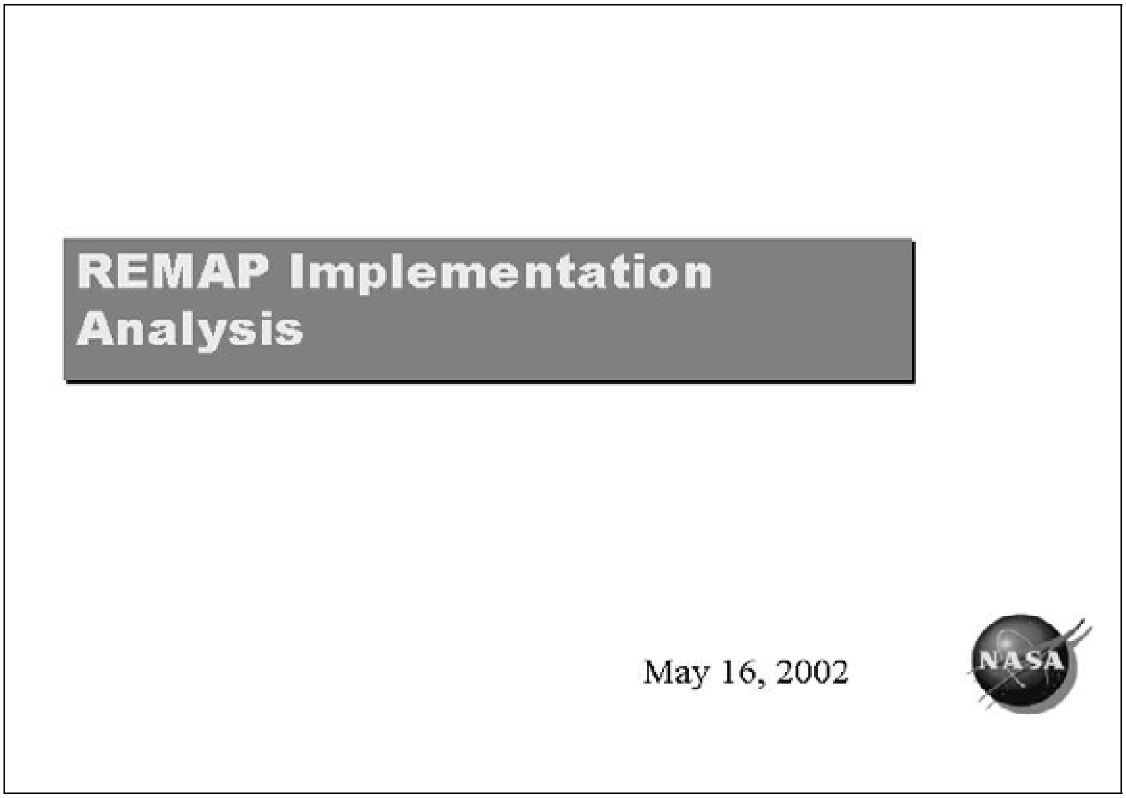
The ReMAP committee incorporated all the OBPR Research Merit Criteria into their prioritization process, but went a level further in deciding the final priorities. Any research that did not have the above components did not make it to highest priority in the first screening. Additional justifications determined by ReMAP for arriving at the Task Force priorities included:

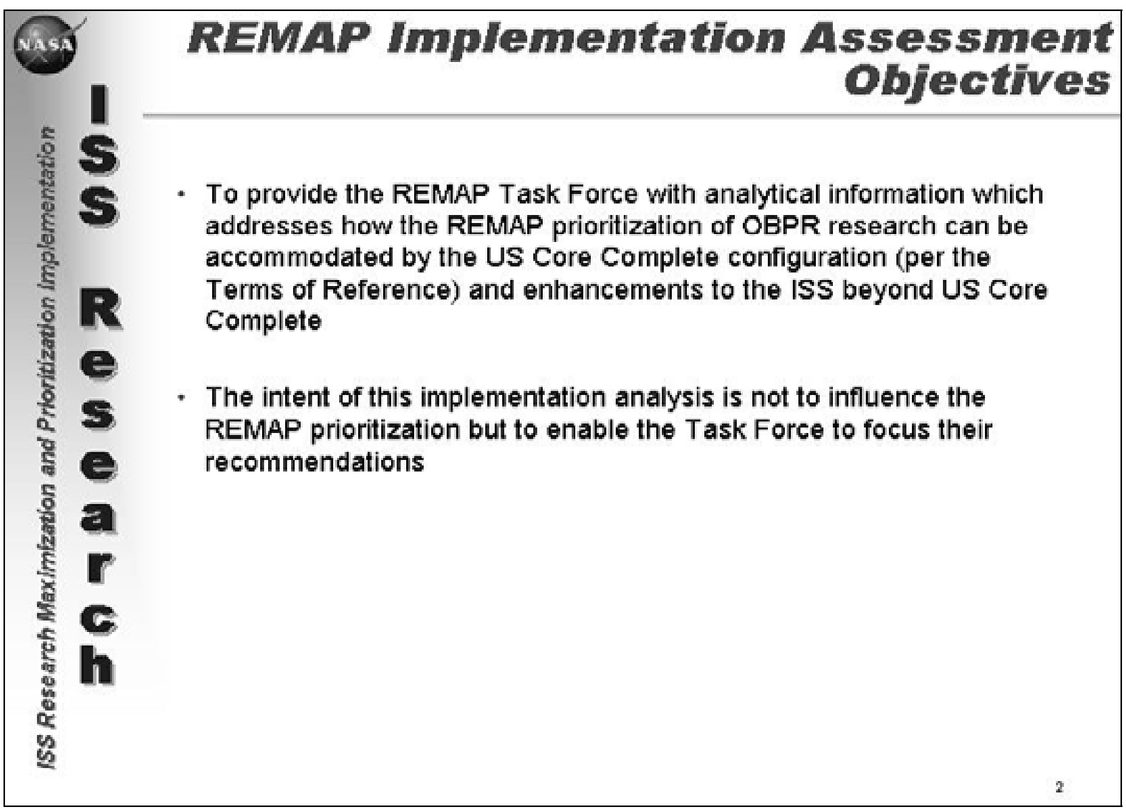
1. For first priority:
   - The research is essential to enable future space exploration.
   - The research could reveal fundamental laws of nature.
   - The research is targeted toward systems with a known direct response to gravity.
   - The research is hypothesis based.
   - The research requires microgravity, human intervention, and long-term access to space.
   - If pertaining to countermeasure development, it is mechanism based.
   - There is potential for substantial increase in capability, efficiency or cost effectiveness as a result of this research.
   - The project enables the development of a new generation of research scholars by training graduate and postdoctoral students.
   - There is a high probability of developing technology and applications that will be useful on earth and in space.
   - There is an effective research community for quality ground- and flight-based research.

2. For second priority:
   - The research effectively utilizes the unique capabilities of the ISS.
   - The research lowers flight risks, improves training and enhances performance of astronauts and equipment.
   - The research provides better understanding of critical areas in which we already have reliable theories and/or data.
   - The research tests whether the system has a direct response to gravity, or requires access to microgravity to be continued.

3. For third and fourth priorities:
   - There has been negative or unclear past experience with this type of space research so that the basic hypothesis now appears questionable.
   - NASA is not the appropriate funding agency – it is not in NASA's mission.
   - NASA can draw heavily or entirely on other agency's research. Others are better able to do the research.
   - The requirement for space-based research in microgravity or for ISS is not evident.

APPENDIX M: OBPR Implementation Analysis





ISS Research

ISS Research Maximization and Prioritization Implementation

Considerations for the Task Force

This briefing highlights the implications that the prioritized research has on critical ISS resources.

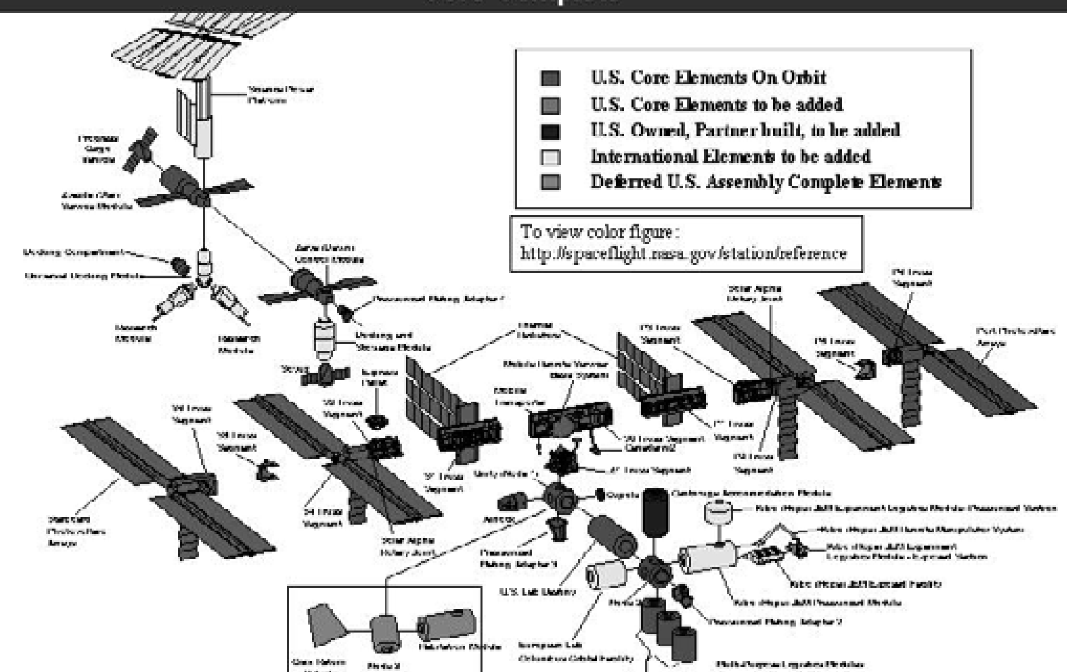
The task force may want to consider the following questions over the course of this briefing:

- Given a significant number of "Priority 1" research areas, the task force may want to consider the extent to which these high priority research areas can be further stratified, given scientific merit, impact to broader community, relevance to NASA's mission, etc.
- Given NASA's commitment to "science-driven decisions," is there a message that the task force wants to send regarding the science requirements to be levied on the ISS, and the order and/or timeframe in which those requirement should be addressed?
- Given the science priorities, does the task force see gaps in OBPR plans for research hardware development?
- Given near term ISS constraints, the task force may want to consider if there are research areas within the "Priority 1" family that should take precedence, at least for the near term.
- Does the task force want to make any statement regarding International Partner capabilities as they relate to NASA's ability to address the science priorities?

3

International Space Station

President's Fiscal Year 2003 Budget "Core Complete"



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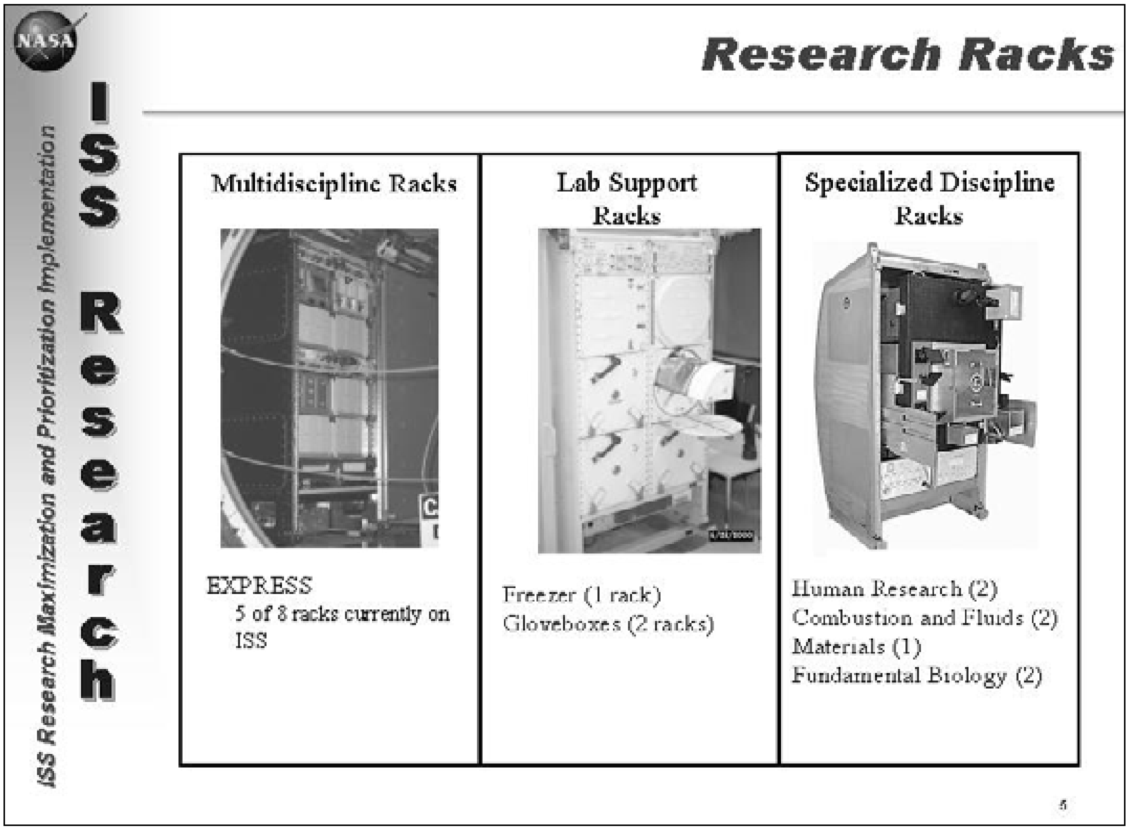
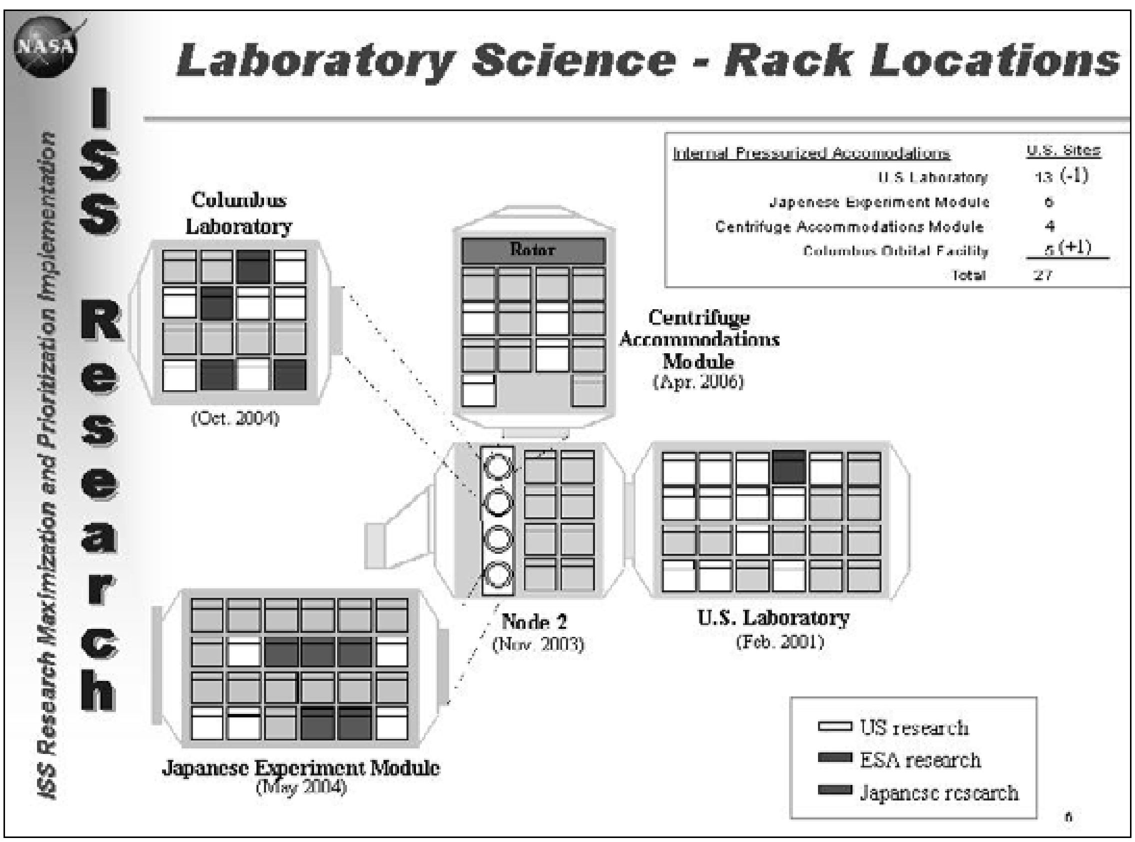
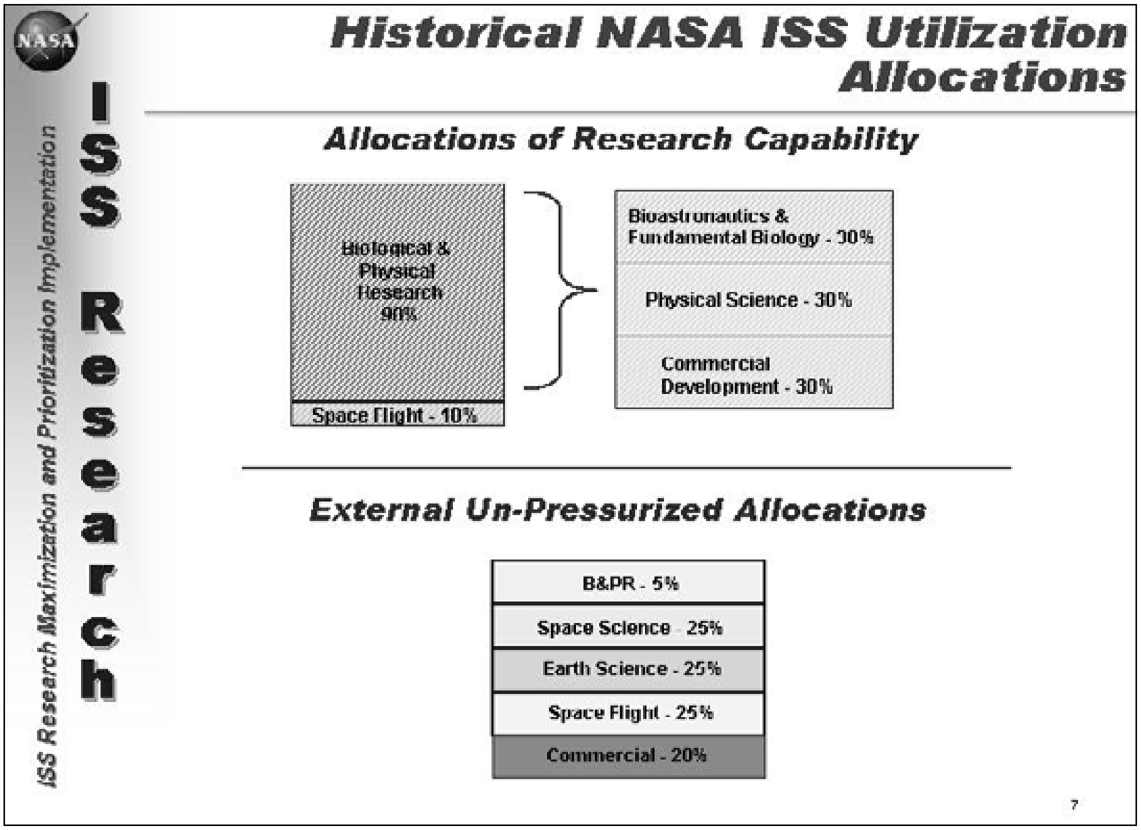
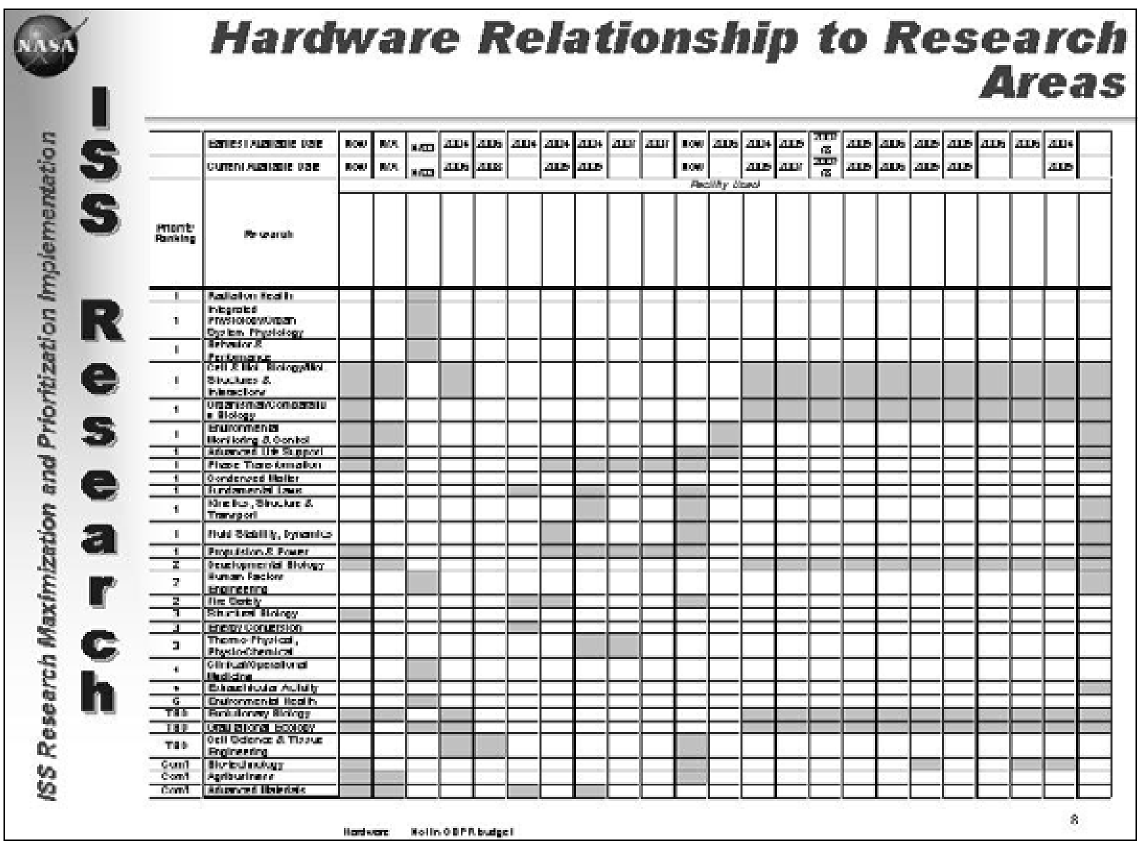

Research Racks
ISS Research
ISS Research Maximization and Prioritization Implementation
Multidiscipline Racks
Lab Support Racks
Specialized Discipline Racks
EXPRESS
5 of 8 racks currently on ISS
Freezer (1 rack)
Gloveboxes (2 racks)
Human Research (2)
Combustion and Fluids (2)
Materials (1)
Fundamental Biology (2)
5


Laboratory Science - Rack Locations
ISS Research
ISS Research Maximization and Prioritization Implementation
Internal Pressurized Accomodations
U.S. Sites
U.S Laboratory 13 (-1)
Japenese Experiment Module 6
Centrifuge Accommodations Module 4
Columbus Orbital Facility 5 (+1)
Total 27
Columbus Laboratory
(Oct. 2004)
Rotor
Centrifuge Accommodations Module
(Apr. 2006)
Node 2
(Nov. 2003)
U.S. Laboratory
(Feb. 2001)
Japanese Experiment Module
(May 2004)
US research
ESA research
Japanese research
6


ISS Research
ISS Research Maximization and Prioritization Implementation
Historical NASA ISS Utilization Allocations
Allocations of Research Capability
Biological & Physical Research 90%
Space Flight - 10%
Bioastronautics & Fundamental Biology - 30%
Physical Science - 30%
Commercial Development - 30%
External Un-Pressurized Allocations
B&PR - 5%
Space Science - 25%
Earth Science - 25%
Space Flight - 25%
Commercial - 20%
7


ISS Research
ISS Research Maximization and Prioritization Implementation
Hardware Relationship to Research Areas
Earliest Available Date
Current Available Date
Facility Used
Priority Ranking
Research
Radiation Health
Integrated Physiology/Human System Physiology
Behavior & Performance
Cell & Mol. Biology/Mol Structures & Interactions
Organismal/Comparative Biology
Environmental Monitoring & Control
Advanced Life Support
Phase Transformation
Condensed Matter
Fundamental Laws
Kinetics, Structure & Transport
Fluid Stability, Dynamics
Propulsion & Power
Developmental Biology
Human Factors Engineering
Fire Safety
Structural Biology
Energy Conversion
Thermo-Physical, PhysicoChemical
Clinical/Operational Medicine
Extravehicular Activity
Environmental Health
Evolutionary Biology
Gravitational Ecology
Cell Science & Tissue Engineering
Biotechnology
Agribusiness
Advanced Materials
Hardware Not in OBPR budget
8

ISS Research Maximization and Prioritization Implementation

ISS Research

Research Area Requirements

- Research in any one area can be performed to differing degrees; in order to bound the resulting range of requirements, various levels of research were defined and requirements estimated for each level.
- Three levels of research used for this analysis
  - ✓ ***Viable*** - A minimal level of research below which "its just not worth doing". This level will represent a minimum hardware and resource requirement.
  - ✓ ***Nominal*** - A level of research activity which will fully address the goals and questions within the research area. This level should not be constrained by any perception of resource constraints.
- Research requirements were defined **per increment**.
  - ✓ An increment on ISS begins with the arrival of a new crew and ends when they return to Earth
  - ✓ Current plan is for 2 increments per year (180 days per increment)

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ISS Research Maximization and Prioritization Implementation

ISS Research

Critical Resources for ISS Research

- *Crew time:* Time that the ISS crew spends on research related activities
- *Resupply upmass:* Mass delivered to the ISS for payload / experiment operations
- *Powered middeck lockers:* Containers provided by the Shuttle for delivering perishable samples or material that must be loaded shortly before launch

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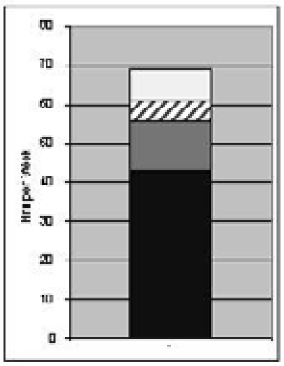
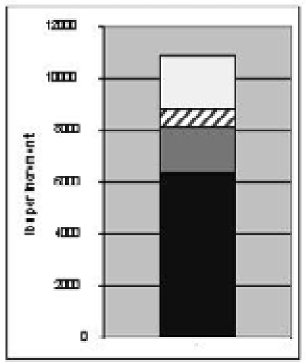
ISS Research

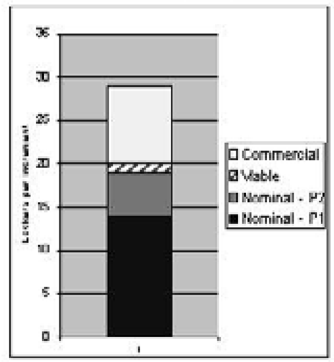
ISS Research Maximization and Prioritization Implementation

Integrated Requirements to Perform OBPR Research

- Assumptions
  - ✓ Perform 1st and 2nd Priorities at nominal Level
  - ✓ Perform 3rd Priority and lower at viable level
  - ✓ Perform commercial at nominal level







Observation:
Crew time for NASA + IP research ~150 hrs per week

Observation:
Equivalent to 3 Shuttle flights dedicated to research per increment

Observation:
Significantly exceeds current allocation

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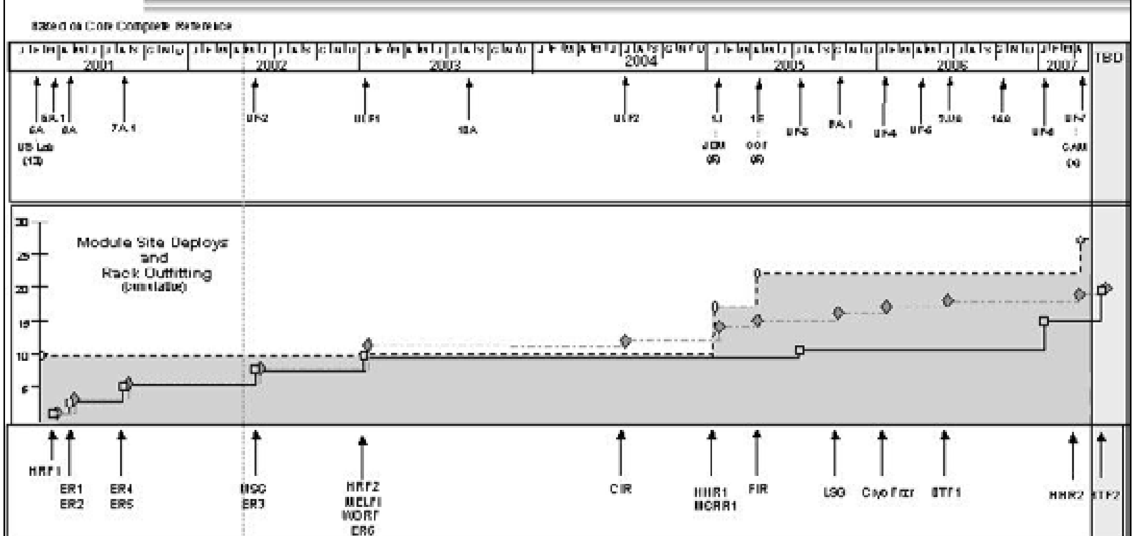
Research Hardware Outfitting Current Plan



KEY
- - ◇- - - Module Sites ——□—— Racks - - -◈- - - Rack Launch Readiness

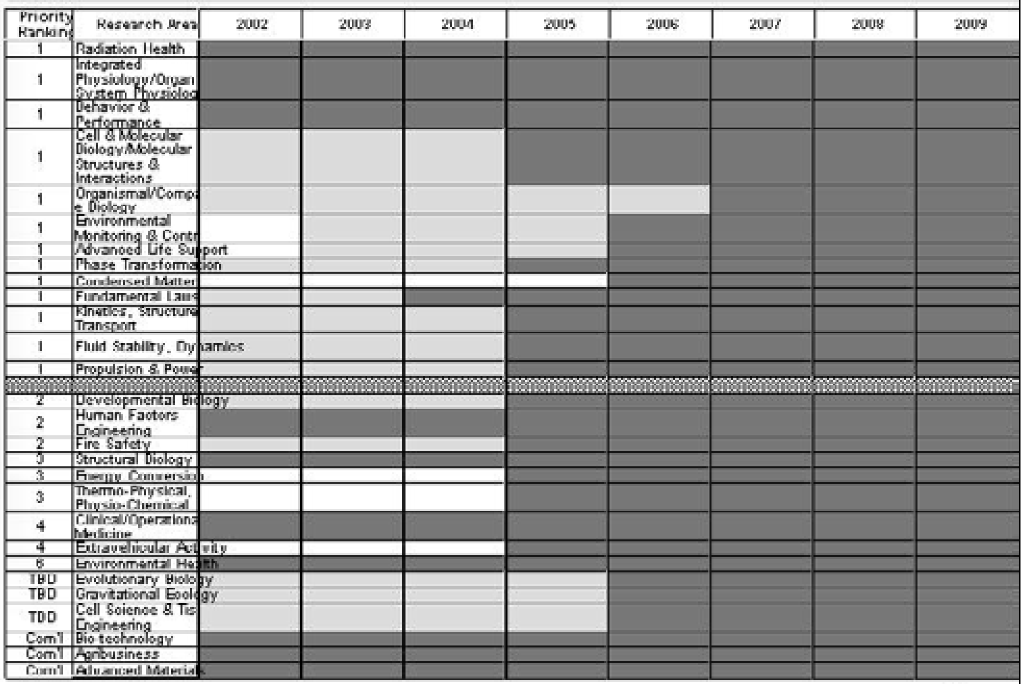
ACRONYMS

BTF:	Biotechnology Facility	FIR:	Fluids Integrated Rack	MSRR:	Materials Science Research Rack
CAM:	Centrifuge Accommodation Module	JEM:	Japanese Experiment Module	MSG:	Microgravity Sciences Glovebox
CIR:	Combustion Integrated Rack	HHR:	Habitat Holding Rack	MELFI:	Minus Eighty Degree Life Sciences Freezer
COF:	Columbus Orbital Facility	HRF:	Human Research Facility	WORF:	Window Observational Facility
ER:	EXPRESS Rack	LSG:	Life Sciences Glovebox		

ISS Research

ISS Research Maximization and Prioritization Implementation

Hardware Constraints on Initiating Priority Research



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ISS Research

ISS Research Maximization and Prioritization Implementation

Research Hardware Observations

- **Planned hardware that is critical only for lower priority research areas (<3):**
  - ✓ Biotechnology Facility (2 racks)
- **Hardware that is not currently funded:**
  - ✓ Plant and Rodent habitats critical for full research in two Priority 1 research areas:
    - ➢ Cellular and Molecular Biology / Molecular Structures and Interactions
    - ➢ Organismal / Comparative Biology
  - ✓ Materials Science Research Racks 2 & 3 critical for full research in two Priority 1 research areas:
    - ➢ Phase Transformation
    - ➢ Power and Propulsion
  - ✓ Combustion Integrated Rack critical for research in some elements of Fundamental Laws research area (Priority 1)
  - ✓ Advanced Human Support Technology rack critical for full research in two Priority 1 research areas
    - ➢ Environmental Monitoring and Control
    - ➢ Advanced Life Support

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ISS Research Maximization and Prioritization Implementation

ISS Research

Research Hardware Provided by International Partners

- A majority of Priority 1 Research areas anticipate use of International Partner-provided hardware
  - ✓ **Japan**
    - ➢ Centrifuge Rotor, Centrifuge Accommodations Module & Life Sciences Glovebox
    - ➢ Aquatic Habitat
  - ✓ **Canada**
    - ➢ Insect Habitat
  - ✓ **European Space Agency**
    - ➢ Force Dynamometers
    - ➢ Percutaneous Electrical Muscle Stimulator
    - ➢ Muscle Atrophy Research and Exercise System
    - ➢ Pulmonary Function System
    - ➢ Fluid Science Laboratory
    - ➢ Electrostatic Levitator
    - ➢ Electromagnetic Levitator
  - ✓ **Germany**
    - ➢ Eye Tracking Device
    - ➢ Lower Body Negative Pressure Device
  - ✓ **France**
    - ➢ DECLIC (Critical Phenomena Experimental Apparatus)

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ISS Research Maximization and Prioritization Implementation

ISS Research

External Attached Payloads

- Two research areas plan to use research payloads that are attached to the ISS outside of the laboratory modules
  - ✓ Condensed Matter (100% of research content)
  - ✓ Fundamental Laws (50% of research content)
- An additional major external research payload, the Alpha Magnetic Spectrometer, is in development
  - ✓ Management assigned to OBPR, but not integrated into the Physical Sciences priorities
  - ✓ Expected launch date ~2006
- These payloads are not factored into the following assessment, but in general represent competition for outfitting the laboratories with research hardware

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ISS Research Maximization and Prioritization Implementation

ISS Research

ISS Configurations Considered

- Three configurations were defined for the purpose of bounding the range of implementation possibilities.
- This assessment focused on the steady state operations for these configurations.

Configuration	Description	Labs on Orbit	Crew Time Available for <u>All</u> Research
U.S. Core Complete (2004)	Build through Node 2	US Lab (12 research racks)	20 hours per week (40 hrs also evaluated)
ISS Core Complete (2007/2008)	Build through Centrifuge Accommodations Module (CAM)	US Lab (13 racks) Japanese Lab (5 racks) European Lab (5 racks) CAM (4 racks)	20 hours per week (40 hrs also evaluated)
Enhanced	Build through CAM + Additional Crew Support Systems	US Lab (13 racks) Japanese Lab (5 racks) European Lab (5 racks) CAM (4 racks)	160

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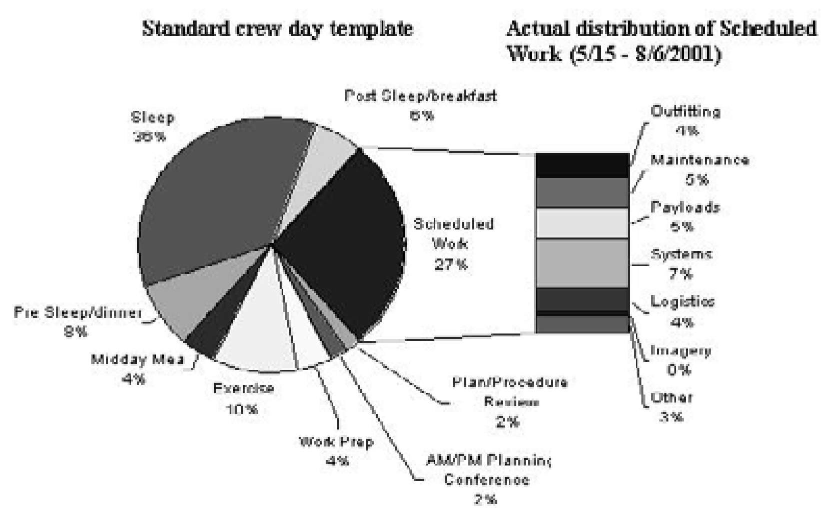
ISS Research Maximization and Prioritization Implementation

ISS Research

Crew Time
Distribution of Crew Activities



ISS Research Maximization and Prioritization Implementation

ISS Research

Crew Time Assumptions and Allocations

Assumptions for Available Research Crew Time (Hours Per Week)

	U.S. Core Complete	ISS Core Complete*	Enhanced**
Total	20.0	20.0	160
Russia	9.8	7.7	61.3
NASA	9.8	7.7	61.3
Europe	0	2.6	20.5
Japan	0	1.7	13.3
Canada	0.5	0.5	3.7
OBPR Allocation	8.8	6.9	55.2
OBPR Allocation (Based on 40 total hours)	17.6	13.9	

* Based on current MOU allocations which assume crew size of 7; if crew size remains at 3 for an extended period, allocations may be renegotiated

**Total available is a rough estimate. Hours per agency are based on current MOU allocations which assume crew size of 7; if end state crew size is 6, allocations may be renegotiated

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ISS Research Maximization and Prioritization Implementation

ISS Research

Upmass and Middeck Lockers - Assumptions and Allocations

Assumptions for Annual Flight Rate to ISS

Configuration	Shuttle	Progress	Japanese HII Transfer Vehicle	European Ariane Transfer Vehicle
U.S. Core Complete	4	4	0	0
ISS Core Complete	5	4	1 (for NASA use)	0.5 (for NASA use)
Enhanced	5	4	2 (for NASA use)	0.8 (for NASA use)

- U.S. Core Complete: If assembly stops at Node 2, some upmass previously dedicated for IP assembly elements can be used for research
- ISS Core Complete & Enhanced
  - ✓ 4 Shuttle + 4 Progress needed to keep ISS vehicle operating and maintained - additional Shuttle flight assumed to provide research upmass
  - ✓ Europe & Japan contribute to the costs of "common" operations / support of ISS
    - ➢ Both are developing vehicles to deliver supplies to ISS to use as the means of "paying" for these obligations
    - ➢ This assessment assumes ESA and NASDA flight rates to meet the current estimate of their obligations
- Current estimates for middeck lockers is 5/shuttle flight - equates to 9 lockers per increment for OBPR research

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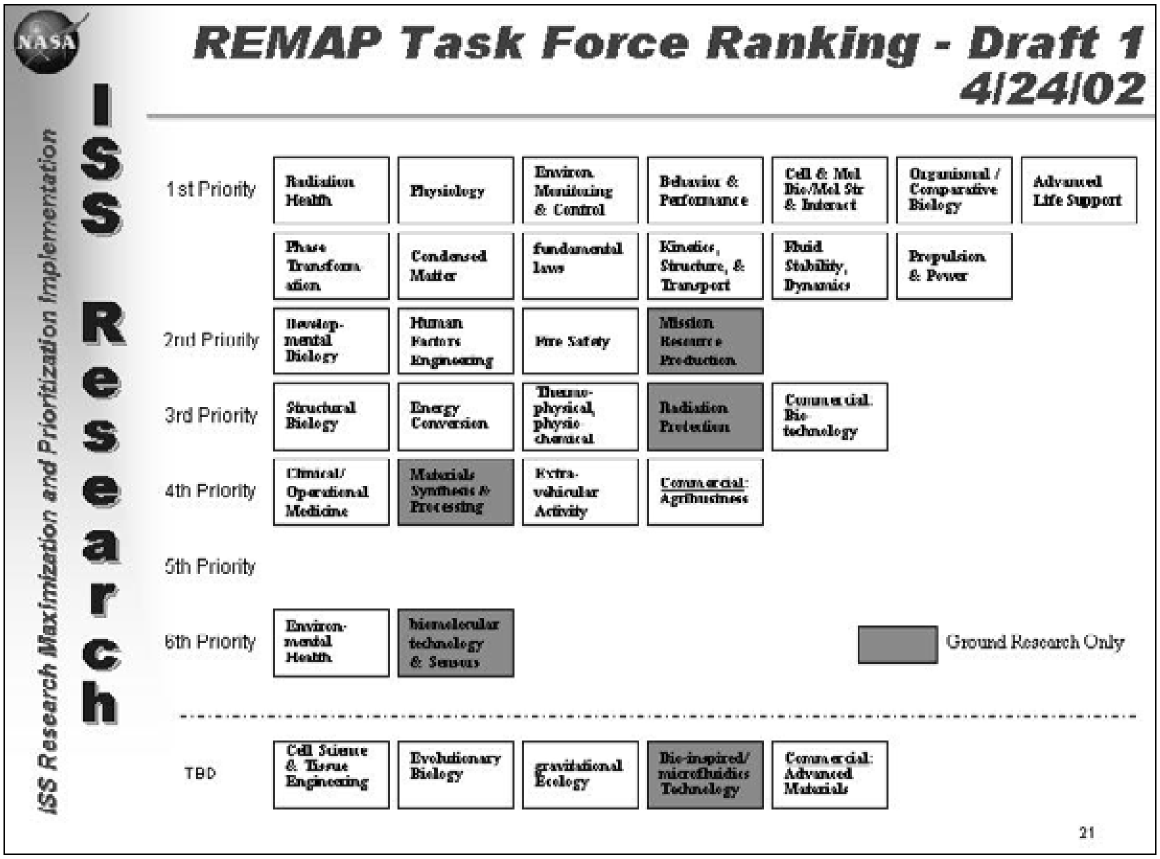
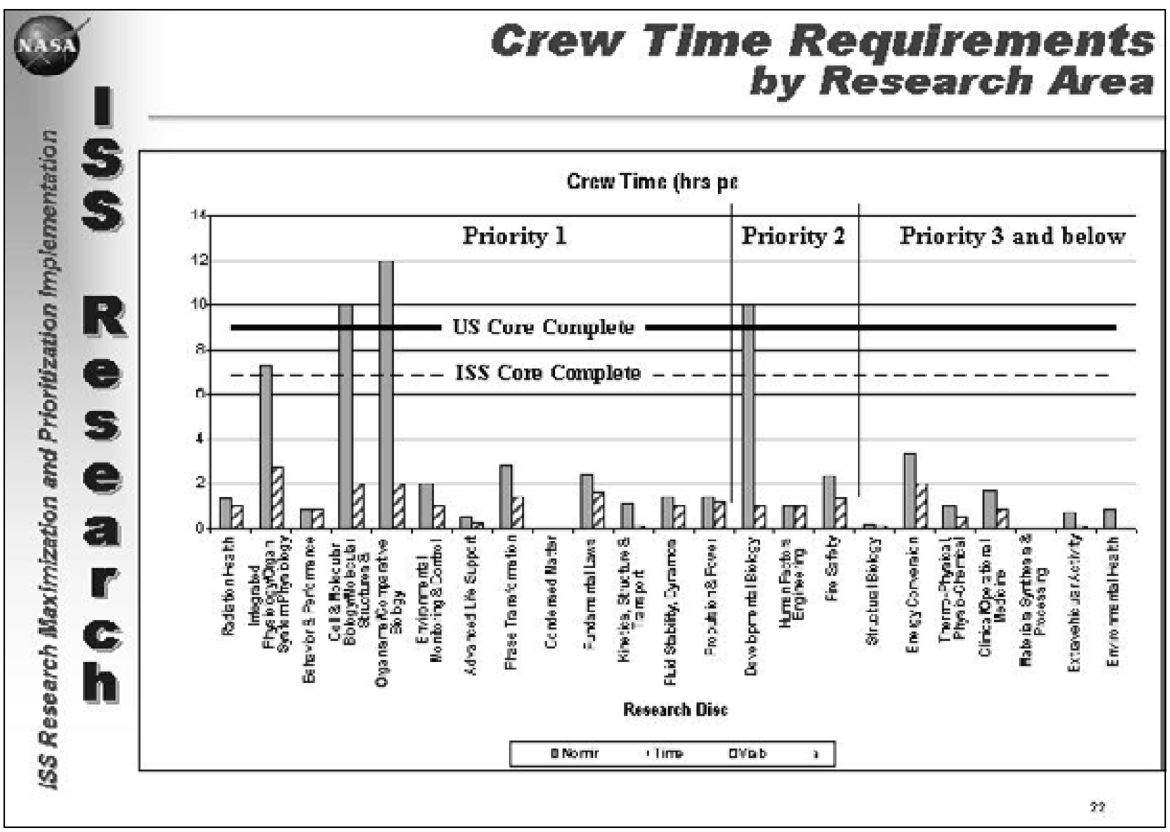
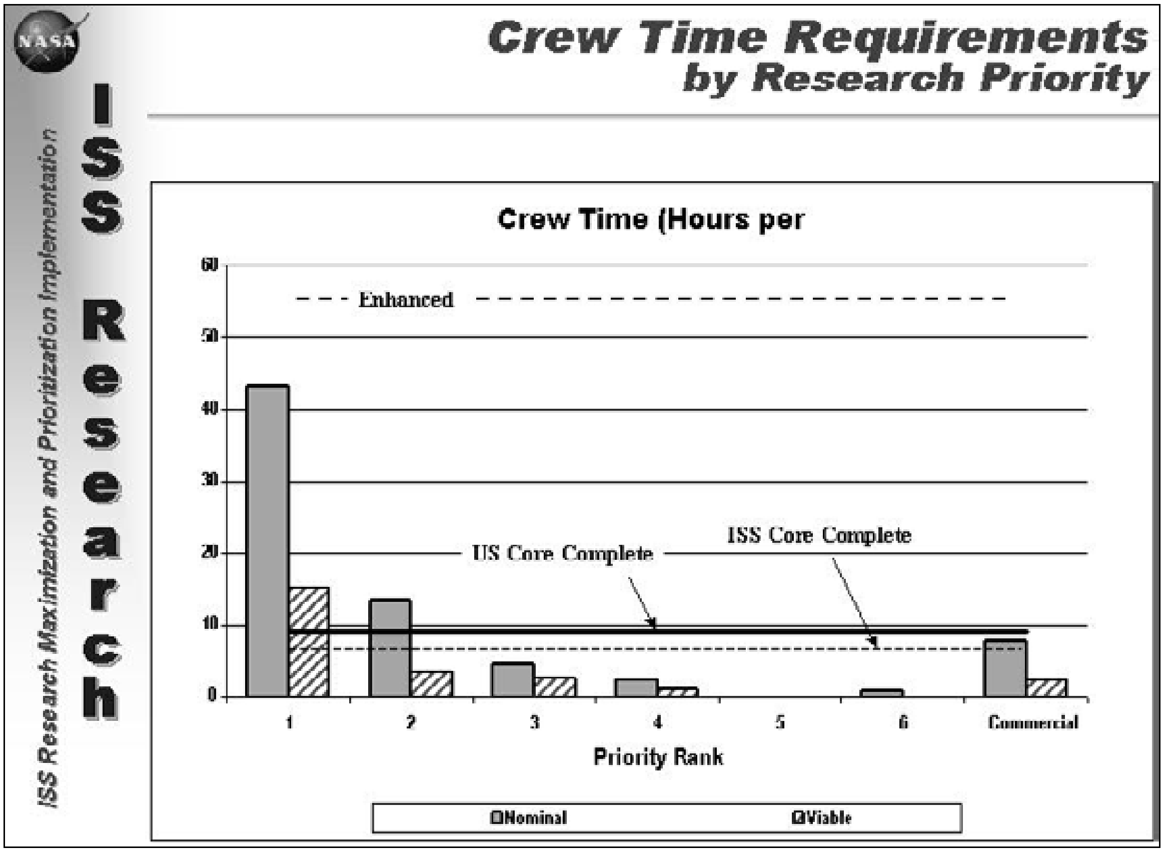
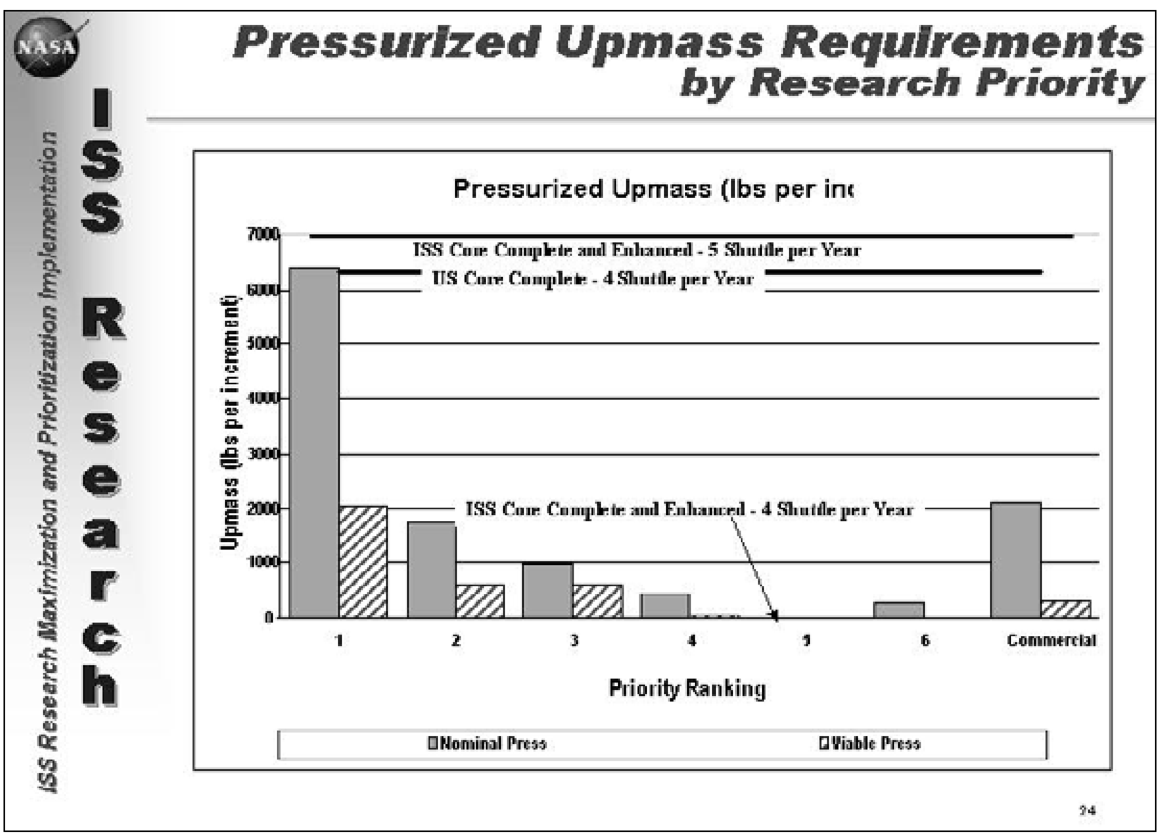

REMAP Task Force Ranking - Draft 1 4/24/02
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transformation
Condensed Matter
fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Develop-mental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
3rd Priority
Structural Biology
Energy Conversion
Thermo-physical, physio chemical
Radiation Protection
Commercial: Bio-technology
4th Priority
Clinical/ Operational Medicine
Materials Synthesis & Processing
Extra-vehicular Activity
Commercial: Agribusiness
5th Priority
6th Priority
Environ-mental Health
biomolecular technology & Sensors
Ground Research Only
TBD
Cell Science & Tissue Engineering
Evolutionary Biology
gravitational Ecology
Bio-inspired/ microfluidics Technology
Commercial: Advanced Materials
21

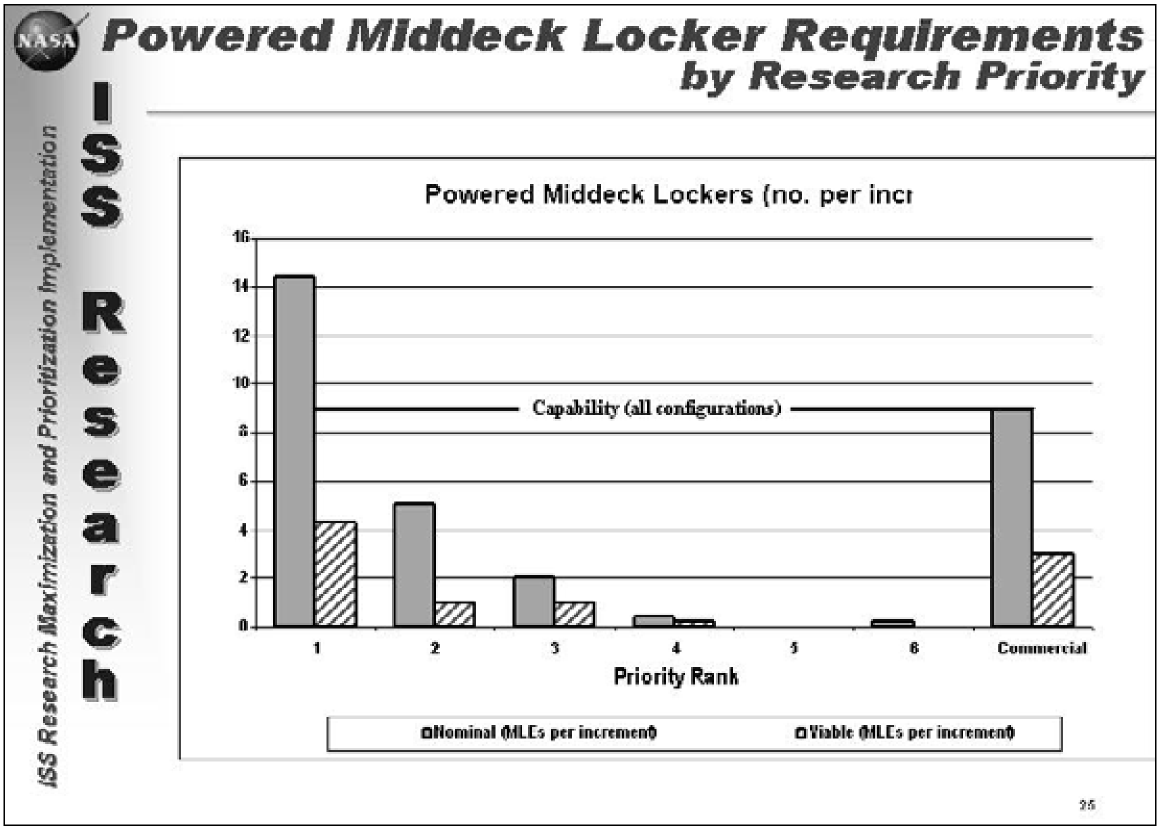

Crew Time Requirements by Research Area
ISS Research
ISS Research Maximization and Prioritization Implementation
Crew Time (hrs pe
Priority 1
Priority 2
Priority 3 and below
US Core Complete
ISS Core Complete
0
2
4
6
8
10
12
14
Radiation Health
Integrated Physiology/Organ System Physiology
Behavior & Performance
Cell & Molecular Biology/Molecular Structures &
Organismal/Comparative Biology
Environmental Monitoring & Control
Advanced Life Support
Phase Transformation
Condensed Matter
Fundamental Laws
Kinetics, Structure & Transport
Fluid Stability, Dynamics
Propulsion & Power
Developmental Biology
Human Factors Engineering
Fire Safety
Structural Biology
Energy Conversion
Thermo-Physical, Physio-Chemical
Clinical/Operational Medicine
Materials Synthesis & Processing
Extravehicular Activity
Environmental Health
Research Disc
22

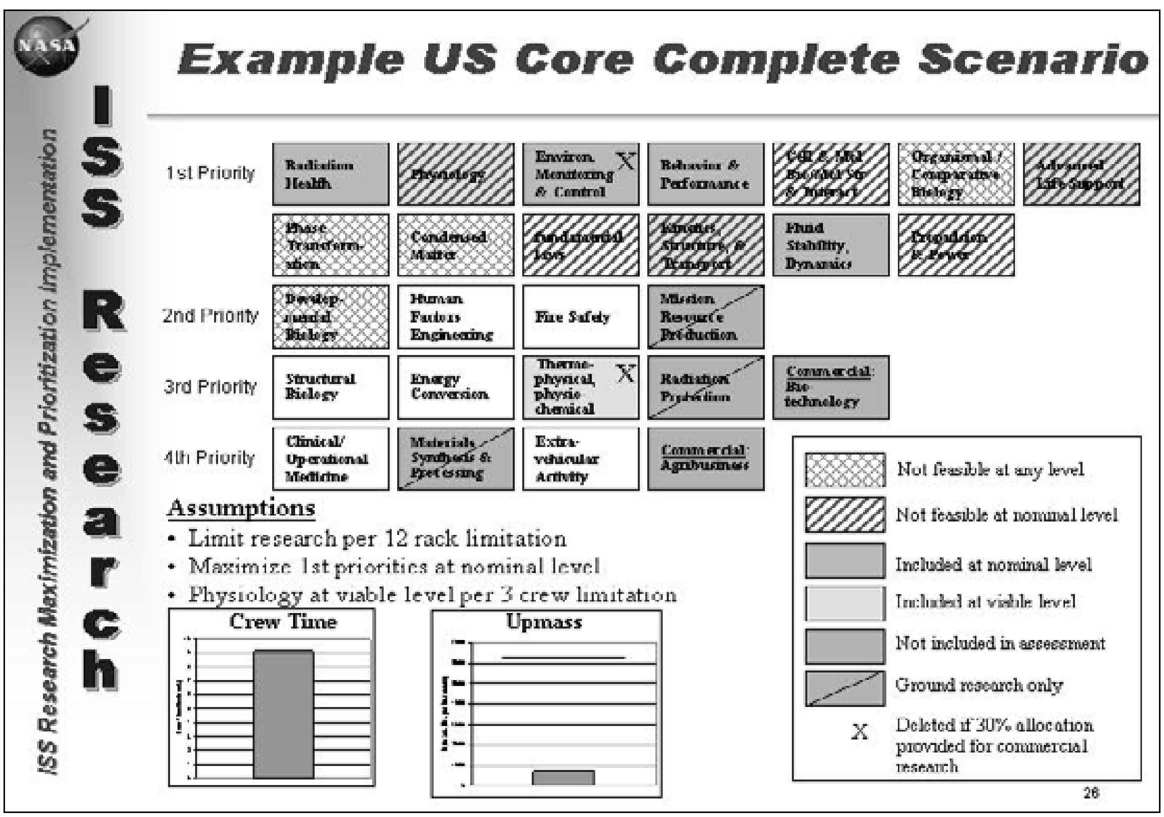


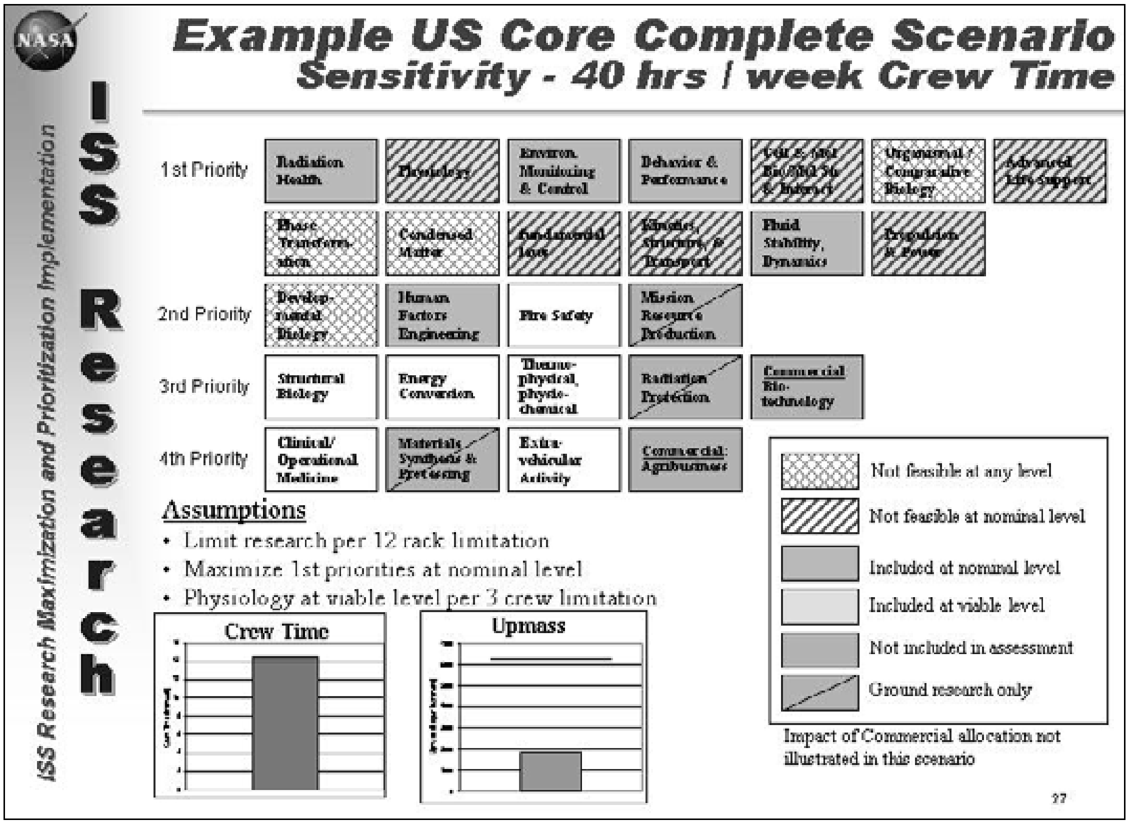
Crew Time Requirements
by Research Priority
ISS Research
ISS Research Maximization and Prioritization Implementation
Crew Time (Hours per
60
50
40
30
20
10
0
Enhanced
US Core Complete
ISS Core Complete
1
2
3
4
5
6
Commercial
Priority Rank
Nominal
Viable



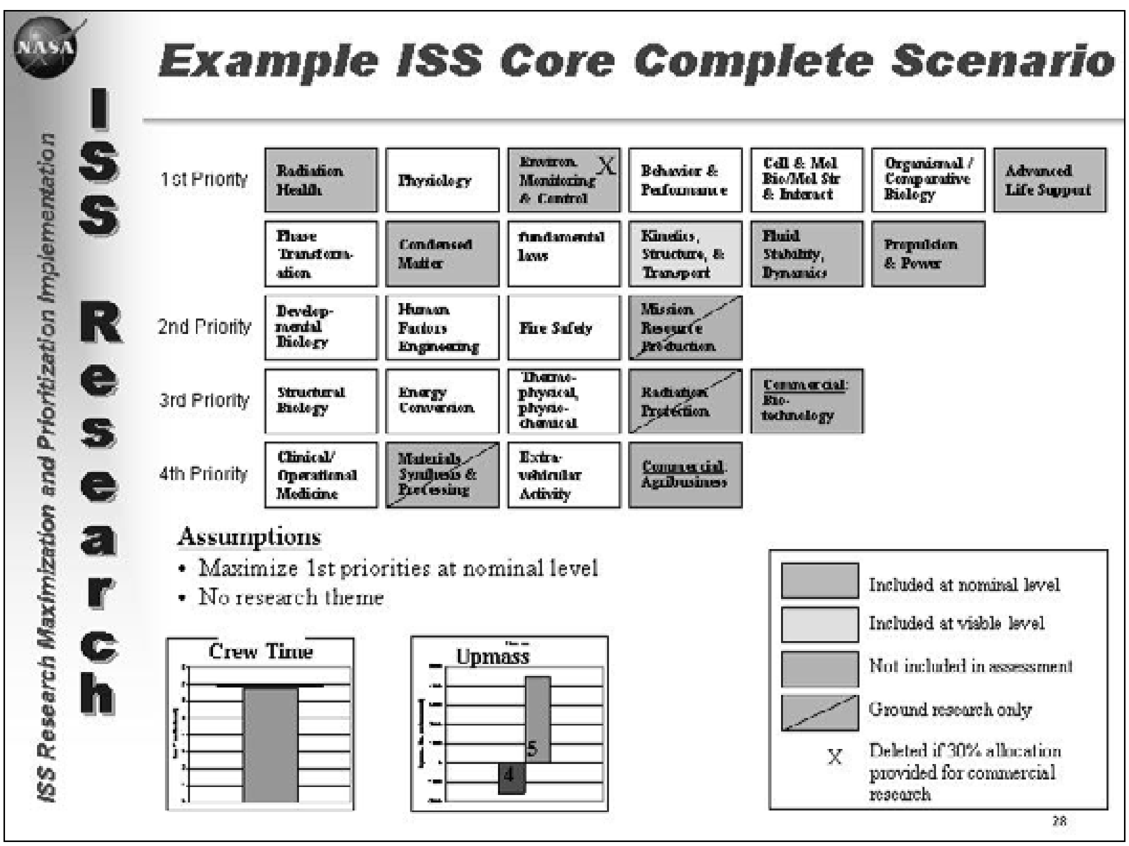
Pressurized Upmass Requirements
by Research Priority
ISS Research
ISS Research Maximization and Prioritization Implementation
Pressurized Upmass (lbs per in
Upmass (lbs per increment)
7000
6000
5000
4000
3000
2000
1000
0
ISS Core Complete and Enhanced - 5 Shuttle per Year
US Core Complete - 4 Shuttle per Year
ISS Core Complete and Enhanced - 4 Shuttle per Year
1
2
3
4
5
6
Commercial
Priority Ranking
Nominal Press
Viable Press
24


Powered Middeck Locker Requirements
by Research Priority
ISS Research
ISS Research Maximization and Prioritization Implementation
Powered Middeck Lockers (no. per incr
Capability (all configurations)
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
Commercial
Priority Rank
Nominal (MLEs per increment)
Viable (MLEs per increment)
25

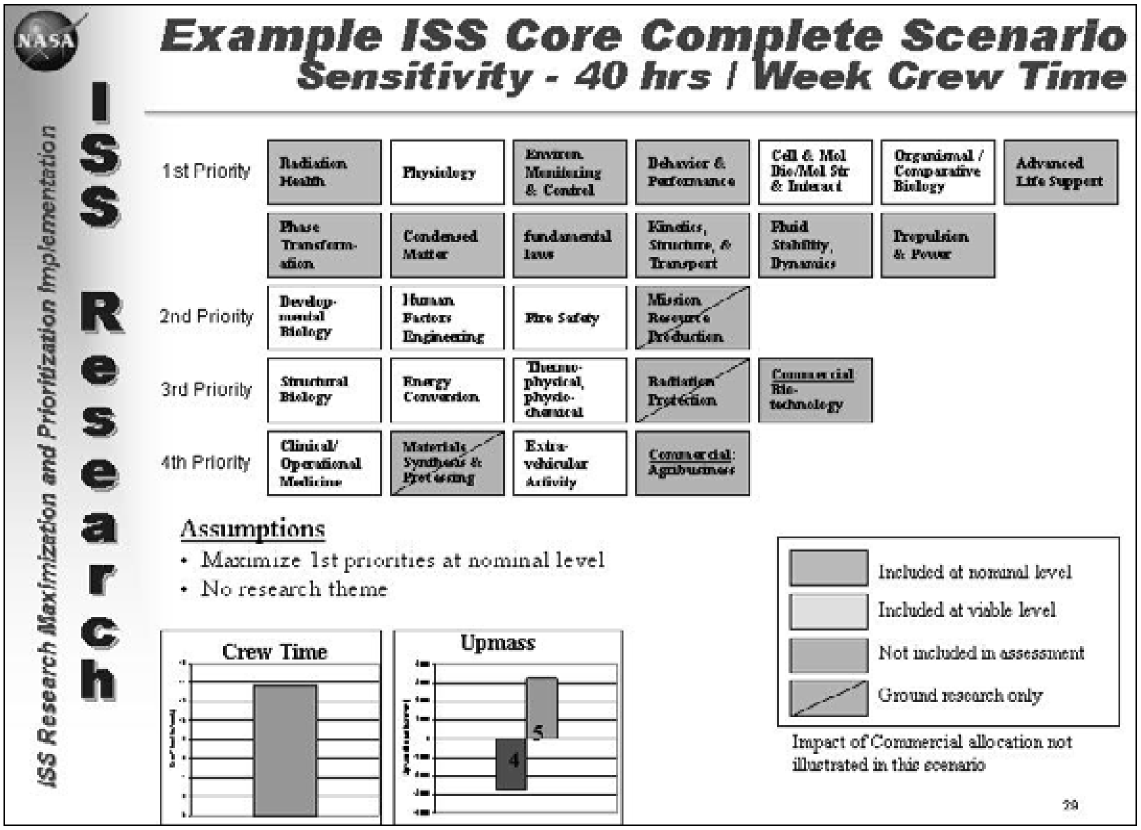

Example US Core Complete Scenario
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
Behavior & Performance
Organismal / Comparative Biology
Advanced Life Support
Phase Transformation
Condensed Matter
Fundamental Laws
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Developmental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
3rd Priority
Structural Biology
Energy Conversion
Thermo-physical, physio-chemical
Radiation Protection
Commercial: Bio-technology
4th Priority
Clinical/ Operational Medicine
Materials Synthesis & Processing
Extra-vehicular Activity
Commercial: Agribusiness
Not feasible at any level
Not feasible at nominal level
Included at nominal level
Included at viable level
Not included in assessment
Ground research only
X
Deleted if 30% allocation provided for commercial research
Assumptions
• Limit research per 12 rack limitation
• Maximize 1st priorities at nominal level
• Physiology at viable level per 3 crew limitation
Crew Time
Upmass
26

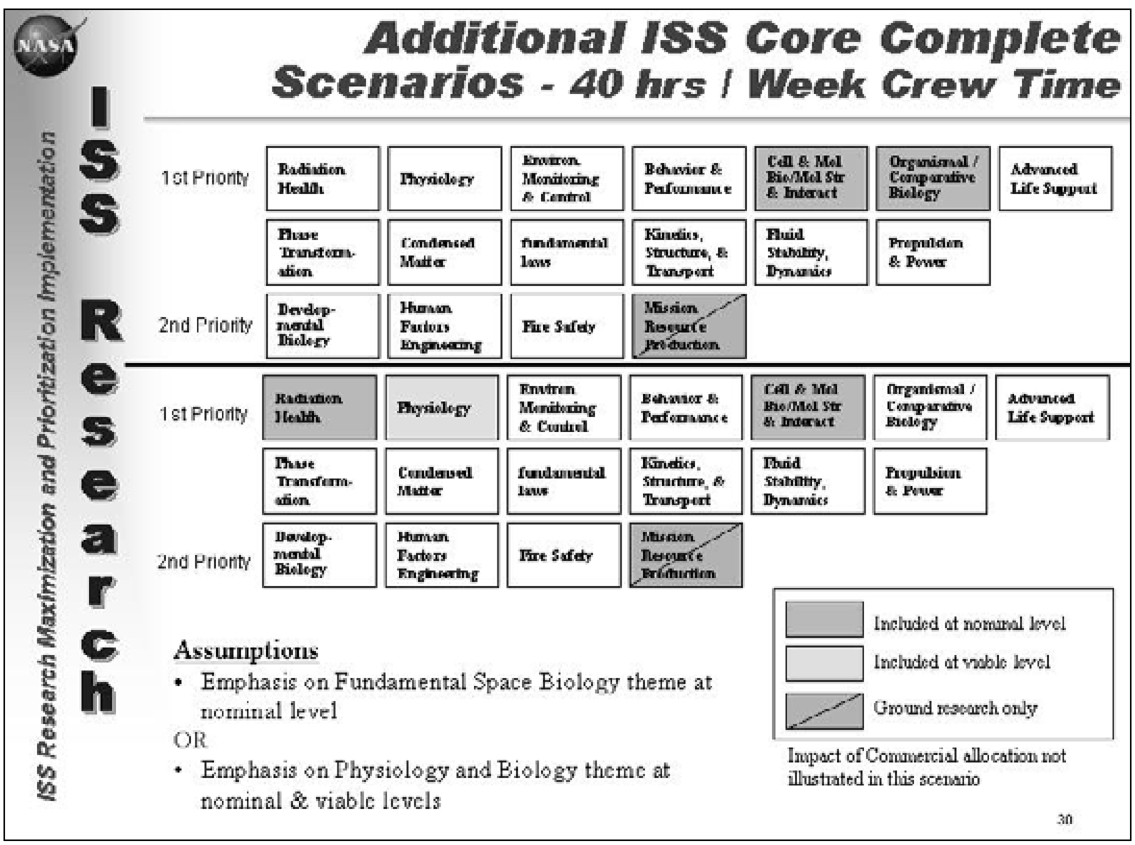


Example US Core Complete Scenario
Sensitivity - 40 hrs / week Crew Time
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transformation
Condensed Matter
Fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Developmental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
3rd Priority
Structural Biology
Energy Conversion
Thermo-physical, physio-chemical
Radiation Protection
Commercial: Bio-technology
4th Priority
Clinical/ Operational Medicine
Materials Synthesis & Processing
Extra-vehicular Activity
Commercial: Agribusiness
Not feasible at any level
Not feasible at nominal level
Included at nominal level
Included at viable level
Not included in assessment
Ground research only
Assumptions
• Limit research per 12 rack limitation
• Maximize 1st priorities at nominal level
• Physiology at viable level per 3 crew limitation
Crew Time
Upmass
Impact of Commercial allocation not illustrated in this scenario
27



Example ISS Core Complete Scenario
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
X
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transformation
Condensed Matter
Fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Developmental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
3rd Priority
Structural Biology
Energy Conversion
Thermo-physical, physio-chemical
Radiation Protection
Commercial: Bio-technology
4th Priority
Clinical/ Operational Medicine
Materials Synthesis & Processing
Extra-vehicular Activity
Commercial: Agribusiness
Assumptions
• Maximize 1st priorities at nominal level
• No research theme
Crew Time
Upmass
5
4
Included at nominal level
Included at viable level
Not included in assessment
Ground research only
X Deleted if 30% allocation provided for commercial research
28


Example ISS Core Complete Scenario
Sensitivity - 40 hrs / Week Crew Time
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transform-ation
Condensed Matter
fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Develop-mental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
3rd Priority
Structural Biology
Energy Conversion
Thermo-physical, physio-chemical
Radiation Protection
Commercial Bio-technology
4th Priority
Clinical/ Operational Medicine
Materials Synthesis & Processing
Extra-vehicular Activity
Commercial: Agribusiness
Assumptions
• Maximize 1st priorities at nominal level
• No research theme
Crew Time
Upmass
4
5
Included at nominal level
Included at viable level
Not included in assessment
Ground research only
Impact of Commercial allocation not illustrated in this scenario
29


Additional ISS Core Complete
Scenarios - 40 hrs / Week Crew Time
ISS Research
ISS Research Maximization and Prioritization Implementation
1st Priority
Radiation Health
Physiology
Environ. Monitoring & Control
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transform-ation
Condensed Matter
fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Develop-mental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
1st Priority
Radiation Health
Physiology
Environ Monitoring & Control
Behavior & Performance
Cell & Mol Bio/Mol Str & Interact
Organismal / Comparative Biology
Advanced Life Support
Phase Transform-ation
Condensed Matter
fundamental laws
Kinetics, Structure, & Transport
Fluid Stability, Dynamics
Propulsion & Power
2nd Priority
Develop-mental Biology
Human Factors Engineering
Fire Safety
Mission Resource Production
Included at nominal level
Included at viable level
Ground research only
Assumptions
• Emphasis on Fundamental Space Biology theme at nominal level
OR
• Emphasis on Physiology and Biology theme at nominal & viable levels
Impact of Commercial allocation not illustrated in this scenario
30

ISS Research Maximization and Prioritization Implementation

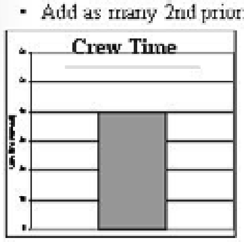
ISS Research

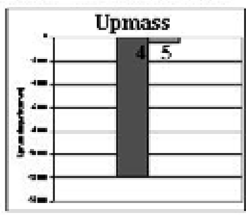
Example Enhanced Scenario

1st Priority	Radiation Health	Physiology	Environ. Monitoring & Control	Behavior & Performance	Cell & Mol Bio/Mol Str & Interact	Organismal / Comparative Biology	Advanced Life Support
	Phase Transformation X	Condensed Matter	fundamental laws X	Kinetics, Structure, & Transport X	Fluid Stability, Dynamics X	Propulsion & Power X	
2nd Priority	Developmental Biology X	Human Factors Engineering X	Fire Safety X	Mission Resource Production			
3rd Priority	Structural Biology	Energy Conversion	Thermo-physical, physio-chemical	Radiation Protection	Commercial Bio-technology		
4th Priority	Clinical/ Operational Medicine	Materials Synthesis & Processing	Extra-vehicular Activity	Commercial: Agribusiness			

Assumptions

- Maximize 1st priorities at nominal level
- Add as many 2nd priorities at nominal or viable level





	Included at nominal level
	Included at viable level
	Not included in assessment
	Ground research only
X	Deleted if 30% allocation provided for commercial research

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ISS Research Maximization and Prioritization Implementation

ISS Research

Considerations for the Task Force

This briefing highlights the implications that the prioritized research has on critical ISS resources.

The task force may want to consider the following questions over the course of this briefing:

- Given a significant number of "Priority 1" research areas, the task force may want to consider the extent to which these high priority research areas can be further stratified, given scientific merit, impact to broader community, relevance to NASA's mission, etc.
- Given NASA's commitment to "science-driven decisions," is there a message that the task force wants to send regarding the science requirements to be levied on the ISS, and the order and/or timeframe in which those requirement should be addressed?
- Given the science priorities, does the task force see gaps in OBPR plans for research hardware development?
- Given near term ISS constraints, the task force may want to consider if there are research areas within the "Priority 1" family that should take precedence, at least for the near term.
- Does the task force want to make any statement regarding International Partner capabilities as they relate to NASA's ability to address the science priorities?

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NASA

ISS Research Maximization and Prioritization Implementation

ISS Research

Back-up Charts

- Acronym List
- Rationale for Using ISS as Primary Research Platform
- Current ISS Research in Flight Manifest
- Integrated Requirements to Perform OBPR Research (2nd Priority @ Viable)

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NASA

ISS Research Maximization and Prioritization Implementation

ISS Research

Acronyms

AHST:	Advanced Human Support Technology
B&PR:	Biological & Physical Research
BTF:	Biotechnology Facility
CAM:	Centrifuge Accommodations Module
CIR:	Combustion Integrated Rack
COF:	Columbus Orbital Facility
ER:	EXPRESS Rack
ESA:	European Space Agency
FCF:	Fluids Combustion Facility
FIR:	Fluids Integrated Rack
JEM:	Japanese Experiment Module
HHR:	Habitat Holding Rack
HRF:	Human Research Facility
IP:	International Partner
ISS:	International Space Station
LSG:	Life Sciences Glovebox
MLE:	Middeck Locker Equivalent
MOU:	Memorandum of Understanding
MSRR:	Materials Science Research Rack
MSG:	Microgravity Sciences Glovebox
MELFI:	Minus Eighty Degree Life Sciences Freezer
NASDA:	National Space Development Agency of Japan
OBPR:	Office of Biological and Physical Research
WORF:	Window Observational Facility

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ISS Research Maximization and Prioritization Implementation

ISS Research

Rationale for Using ISS as Primary Research Platform

Research Area	Primary Needs for Using ISS			
	Crew Intervention/ Crew as a Research Subject	Long Duration Experiment	Repetition of Experiment	Large/Facility Class Hardware
Radiation Health	•	•	•	•
Integrated Physiology/Organ System Physiology	• / •	• / •	• / •	• / •
Behavior & Performance	•	•	•	•
Cell & Molecular Biology/Molecular Structures & Interactions	• / •	• / •	• / •	• / •
Organismal/Comparative Biology	•	•	•	•
Environmental Monitoring & Control	•	•	•	
Advanced Life Support	•	•	•	•
Phase Transformation	•	•	•	•
Condensed Matter		•	•	•
Fundamental Laws	•	•	•	•
Kinetics, Structure & Transport	•		•	•
Fluid Stability, Dynamics	•	•	•	
Propulsion & Power	•	•	•	•
Developmental Biology	•	•	•	•
Human Factors Engineering	•	•	•	
Fire Safety	•		•	•
Structural Biology		•	•	
Energy Conversion	•		•	•
Thermo-Physical, Physio-Chemical	•		•	•
Clinical/Operational Medicine	•	•	•	•
Extravehicular Activity	•		•	
Environmental Health	•	•	•	•
Evolutionary Biology	•	•	•	
Gravitational Ecology	•	•	•	•
Cell Science & Tissue Engineering	•	•	•	•
Com'l: Remote Sensing & Autonomous Systems		•	•	
Com'l: Telecommunications		•	•	
Com'l: Thermal Control		•	•	
Com'l: Power Generation, Storage & Distribution		•	•	
Com'l: Robotics & Structures		•	•	
Com'l: Propulsion		•	•	
Com'l: Bio-technology	•	•	•	
Com'l: Agribusiness		•	•	
Com'l: Advanced Materials		•	•	•

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ISS Research Maximization and Prioritization Implementation

ISS Research

Current ISS Research in Flight Manifest*

Data for Increment 0 through 6

- Increment 4 is on orbit right now, ending June 2
- Increment 6 ends in Jan, 2003

A total of 48 Code U Investigations supported

(not all are complete with a number of subjects or test runs yet).

- 8 or 17% - Commercial
- 23 or 48% - directly from, or indirectly support Priority 1 Research Areas
- 3 or 6% - from Priority 2 Research Areas
- 5 or 10% - from Priority 3 Research Areas
- 2 or 4% - from Priority 4 Research Areas
- 7 or 15% from the TBD area

* Represents first order mapping of PI investigations to research area "boxes".

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APPENDIX N: Statements of Dissent

The ReMAP Task Force strived to achieve unanimity in this report. In the second meeting of the Task Force, on April 22, all but one Task Force member agreed to the priority ranking of the research. Well after the third and final meeting of the Task Force on May 17, further dissent developed, both before and after the ReMAP report was presented on July 10 to the NASA Advisory Committee and the public. The dissenters were invited to write Minority Opinions and/or Statements of Dissent, which are included here. See also Appendix C, charts 66 – 68.

June 4, 2002
COMMENTS ON ReMAP'S FINDINGS AND RECOMMENDATIONS

As a member of the OBPR Research Maximization and Prioritization (ReMAP) Task Group I wish to express my concerns about:

1. The process by which priorities for microgravity research programs were assigned, and

2. The ranking given to the protein crystallization program.

THE PRIORITIZATION PROCESS

From my observations the process used by ReMAP in setting priorities for microgravity research was so biased, superficial and arbitrary as to cast serious doubts on the validity of the panel's findings and recommendations. I believe this came about for the following reasons:

Composition of the Task Group

The selection of the members of ReMAP was biased toward small animal studies and to the proposition that life in space, rather than life on earth, should be the principal rationale for microgravity research.

Many members of the task group had little or no previous experience with NASA's research programs. Perhaps it was intended that this would ensure a fresh outlook but in practice this lack of historical perspective led to less informed decision-making.

Although many of the programs evaluated had a medical or commercial rationale, only a few members of the panel had the requisite expertise to evaluate them.

Time Constraints

The task group was called upon to prioritize current or proposed microgravity research programs in 8 categories, which were divided into 41 programs, many of which were in turn divided into several subprograms. Only two days were allowed for this exercise. The prioritization process was so rushed and the volume of information to digest so voluminous that most programs were evaluated only superficially.

The research programs ReMAP was asked to consider all fall naturally into one of three categories:

1. Human Health and Safety Research
2. Biological and Physical Research
3. Commercial Research

An inordinate amount of time was spent discussing programs in the first category even though all agreed that the health and safety of the crew is of the highest priority. A separate panel of experts in space medicine should have prioritized the programs within this category.

Commercial research was given very short shrift by the task group composed, as it was, mainly of individuals with no industrial experience. A separate panel, of scientists from industry, should have prioritized the programs within this category.

Had the work of ReMAP been divided into three separate, concurrent panels, the discussions would have been more substantive and the prioritization process more valid. There is no need to prioritize among the three categories, because the first is undisputedly a top priority and Congress mandates the third.

<u>Lack of Attention to Previous Peer Reviews</u>

Since there was no time to develop independent evaluations of research programs, previous peer reviews should have been accepted as the basis for setting priorities. This was certainly not done in the case of the protein crystallization program.

Several members who had no previous experience with the program or expertise in crystallography expressed strong negative opinions about its worth. From their comments it was clear that these individuals based their opinions on criticisms they had heard from persons outside the task group.

However, these criticisms were all addressed by a recent NRC report [*Future Biotechnology Research on the International Space Station*, National Academy Press, Washington, D.C., (2000)]. NASA has moved expeditiously to implement the NRC recommendations.

Only three members of ReMAP stated that they had ever seen or read the NRC report. I requested that copies of the report be distributed to all the members before the final meeting, but this was not done. To the extent that the NRC report was considered at all, it was misrepresented and quoted out of context.

<u>Failure to Adhere to a Consistent Set of Prioritization Criteria</u>

The ranking process was arbitrary and chaotic. At the first meeting ReMAP members were given a list of NASA criteria to be used in evaluating the research programs. However, these metrics were totally ignored. No research program was ever formally graded according to that set of criteria or any other.

The prioritization of programs in each of the eight categories was carried out in breakout groups. Any ReMAP member was free to participate in any breakout group, no matter what his or her degree of expertise in the field. The discussions were brief, less than 30 minutes total for all the programs in each category, and tended to be dominated by a few vocal individuals. No votes on rankings were ever taken, even where there was clear disagreement.

RANKING OF THE PROTEIN CRYSTALLIZATION PROGRAM

There is a serious disconnect between reality and the ReMAP findings that ranked protein crystallization in the lower third of all the programs considered.

I believe protein crystallization should be given the highest microgravity science priority on the following bases:

Based on Technical Merit, Accomplishments and Potential

No other program considered by ReMAP has the quantity and quality of favorable attributes:

1. The hypothesis upon which the program rests is sound.
2. The success or failure of any experiment can be easily and precisely determined.
3. The potential social and economic impact of the program is enormous.
4. The program has recently been peer reviewed in great detail.
5. There is a large and supportive user community,
6. Approximately 20% of all proteins flown have shown improvement in crystal diffraction resolution.
7. The program has an impressive record of commercial spin-offs.
8. There have been many fundamental ground-based experiments on protein crystal nucleation and growth.
9. Sophisticated automated experimental hardware has been demonstrated.
10. There is now a very large experimental database available.
11. An extensive educational outreach program has been developed.

Based on NASA's Research Merit Criteria

Since ReMAP ignored the NASA Research Merit Criteria given to us at the first meeting, I have done my own evaluation of the protein crystallization program based on those metrics. I have given each of the 31 criteria listed below a score of 1 to 5, with 1 being the highest.

Giving equal weight to each of the criteria (although clearly some are more important than others) my overall score for the protein crystallization program is 1.8. I doubt that any other scientific program, were it judged by these same metrics, would rank as high.

I. Impact to Broad Scientific and Technological Community.

a. Will the research have significant benefits/applications to ground-based as well as space-based operations involving the basic disciplines or cross-disciplinary interactions?

Improvement in the diffraction resolution of protein crystals can be expected to contribute significantly to fundamental knowledge of biological structures and mechanisms and to the structure-based design of new drugs for human and animal disease and of new chemical agents for the production of food and fiber.
Ranking 1

b. Will the results have broad usefulness, leading to further theoretical, experimental, or commercial and technological developments that have application beyond the particular initiative?

Yes. See I.a. above.
Ranking 1

c. Will the research help demonstrate the benefit of using the environment of space to further the advancement of knowledge or to enhance products and services on Earth?

Yes, the benefit of the microgravity environment has already been shown for at least 36 proteins to yield crystals that diffract to higher resolution than the best grown on earth. It is already NASA's most successful microgravity program.
Ranking 1

d. Is there a potential for stimulation of future technological "spin-offs"?

The Center for Biophysical Sciences and Engineering (CBSE) located at the University of Alabama at Birmingham (a NASA-funded Commercial Space Center) has an impressive commercialization program.

- Four companies have been spun off from CBSE:

  (1) Biocryst Pharmaceuticals, a publicly held company listed on NASDAQ, has 77 employees. CBSE has licensed to Biocryst inhibitors of three target enzymes, all of them in clinical trials. CBSE will receive royalties on any drugs marketed by the company.

  (2) Diversified Scientific, Inc., is commercializing laboratory crystallization technology developed at CBSE.

(3) Ibbex is developing certain medical and research diagnostics, in collaboration with a member of the CBSE staff.

(4) Oculus Pharmaceuticals is developing high throughput crystallization proteomics technology developed at CBSE.

- CBSE has grown in microgravity crystals of an anti-infective target enzyme that show significantly higher diffraction resolution than the best grown on earth. This has resulted in collaboration with an undisclosed biotechnology company for development of inhibitors of the enzyme.

- In addition, CBSE has supported and/or participated in a number of instrumentation development collaborations with the private sector for technology needed for microgravity experiments.

<u>Ranking 1</u>

e. Will the value of the product if or when it is realized in an application be timely?

This is the biggest challenge the protein crystallization program faces. In order to match the pace of structural biology and drug-design research, the process for growing crystals in microgravity must be speeded up and made more user friendly. The number of crystallization experiments must be greatly increased and crystals must be preserved by cryo-freezing while they are fresh.

<u>Ranking 3</u>

f. Will the research stimulate integration or combination of now separate concepts or information?

Probably not.

<u>Ranking 5</u>

g. Will the research results be applicable or beneficial to an area not immediately related to the field of research?

Possibly. Some hardware developed for protein crystallizations on ISS may be used in analytical and diagnostic testing in ground-based laboratories.

<u>Ranking 3</u>

h. What is the impact on existing international agreements?

The European and Japanese space agencies have an active interest in protein crystallization and have designed and flown apparatus on the Space Shuttle. There are probably other current or potential international collaborations, but I don't know the particulars.

<u>Ranking 1</u>

i. Is there potential for economic impact?

The economic potential is extraordinarily high. The annual sales of many drugs exceed one billion dollars and some are several times that. It is not unreasonable to assume that the lifetime market value of a single important drug designed using data from protein crystals grown in microgravity could exceed the entire cost of the ISS.
Ranking 1

II. Science Importance

a. Are the key scientific questions addressed by the specific research important?

Protein crystallization is of course a means to an end. The end, an understanding of biological structures and mechanisms and the design of drugs, is extraordinarily important.
Ranking 1

b. Does the research represent a groundbreaking advance or is it incremental relative to state-of-the-art?

In most cases the enhancement in diffraction resolution will be incremental. But even incremental improvements in resolution are very important in structure-based drug design research, where one is looking for the position of a smallmolecular needle in a large macromolecular haystack.
Ranking 1

c. Is there a potential for insight into previously unknown phenomena, processes, or interactions?

NASA has already supported a number of ground-based experiments that have yielded important insights into the process of macromolecular crystal nucleation and growth. This body of research is one of the strong points of the program.
Ranking 1

d. Is the research a significant contribution to timely issues, or just buzzword compliant?

Structural biology and drug design are currently two of the hottest areas of scientific inquiry.
Ranking 1

e. Will the research provide powerful new techniques for observing nature?

Although x-ray diffraction is not a new technique, the availability of higher diffracting crystals will certainly improve our picture of nature. If slow diffusion controlled crystal growth of very large macromolecular complexes is as important as many believe, then

microgravity may help open a whole new window on nature, i.e., the structures of integral membrane receptors and membrane-bound complexes.
Ranking 2

f. Will the research answer fundamental questions or stimulate theoretical understanding of fundamental processes or structures?

Yes. See I.a, above.
Ranking 1

g. Is there potential for an important advance in knowledge or understanding in areas at the boundaries between disciplines?

X-ray crystallography is a field which itself spans the boundaries between physics, chemistry and biology. Indeed many of today's structural biologists started their careers in one of those three fields before taking up crystallographic research.
Ranking 1

III. Contributions to National Goals

a. Will the research contribute to national pride and to the image of the United States as a scientific and technological leader because of the magnitude of the challenge, the excitement of the endeavor, or nature of the results?

The United States is already recognized as the world leader in drug research. The protein crystallization program can be expected to contribute to this position.
Ranking 1

b. Will the research contribute to education by generating student interest in science or by attracting students to science and engineering?

NASA has sponsored an exciting educational outreach program in protein crystallization through the University of California at Irvine. Students and teachers, working in their school classrooms and laboratories, are given an opportunity to learn about and to set up crystallizations of some of the same proteins being flown on the Space Shuttle. As of April 2002, more than 50,000 students and 1090 teachers from 320 schools across 36 states and Puerto Rico had participated though workshops and classroom and laboratory activities. Several hundred students and teachers have helped prepare the actual samples for four recent Space Shuttle flights.
Ranking 1

c. Will the research aid in fostering of commercialization of space?

If the protein crystallization facility on International Space Station is as successful and as user friendly as I believe it could be, many pharmaceutical and biotechnology companies are likely to want to participate. There might even be consortia of companies formed to

build and operate facilities for proprietary research on ISS. A model for such a consortium is that formed by twelve pharmaceutical companies to build and operate x-ray beamlines at the Advanced Photon Source synchrotron at Argonne National Laboratory.
<u>Ranking 1</u>

d. Will the research present opportunities for cooperation with external organizations including international partners?

Such cooperation already exists. See I.h. above.
<u>Ranking 1</u>

e. Will the research engage and involve the public in research in space?

NASA's educational outreach program at the University of California at Irvine is an important step in that direction. See III.b. above.
<u>Ranking 1</u>

f. *Will the research contribute to public understanding of the natural world and appreciation of the goals and achievements of science?*

Protein crystallography is one of the most esthetically pleasing of all sciences. Who does not appreciate the beauty of crystals, the symmetry of lattices or the elegance of a protein structure? Modern computers, graphic displays and three-dimensional animation software have made it possible to open to public understanding the world of complex molecular structures and their interactions. But it all starts with crystals that diffract to high resolution.
<u>Ranking 1</u>

g. Will the research benefit the economic health of this nation?

Yes. Vastly more than any other microgravity research yet proposed. The U. S. pharmaceutical industry is one of the biggest positive contributors to the nation's balance of trade. See also I.i. above.
<u>Ranking 1</u>

IV. Vital to NASA's Mission

a. Will the research substantially contribute to the health, safety, and performance of humans living and working in space?

Yes, in the same way that it will benefit all humans.
<u>Ranking 3</u>

b. Will the research enhance ISS productivity?

Possibly, through the development of robotics and remote visualization hardware and software that might be applicable elsewhere on ISS.
Ranking 3

c. Is the space environment of fundamental importance to the research, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter, or in providing access to conditions not available on Earth?

Absolutely. The rationale for growing protein crystals in microgravity is based on the hypothesis that such crystals will be more highly ordered and therefore diffract x-rays to higher resolution. As a crystal grows it depletes the solute in the surrounding solution, creating what is known as a 'depletion zone' around the crystal.

On earth the less dense depletion zone continually dissipates due to the mixing with the higher density bulk solution. This disruption of the equilibrium around the growing crystal results in some solute molecules being laid down in a disordered manner.

In microgravity, however, there is little disruption of the depletion zone. Solute molecules from the bulk solution diffuse slowly through the zone and are laid down on the growing crystal in a more ordered manner.
Ranking 1

d. Will the research substantially contribute to the safety and effectiveness of robotic exploration missions?

No.
Ranking 5

e. Does the research require a NASA-unique ground-based facility or expertise?

NASA has assembled an excellent support staff at Marshall Space Flight Center and funded private companies and university laboratories to assist investigators in flying samples on Space Shuttle.
Ranking 3

f. Does the research advance and communicate scientific knowledge and understanding of the Earth, the solar system, or the universe?

Not specifically about the earth itself, but certainly about life on earth.
Ranking 3

g. Does the research expand advanced aeronautics, space science, or space technology?

No.

Ranking 5

h. *Does this research support NASA's goal to foster the commercial use of space?*

Very strongly! See I.a., I.d. and I.i. above.
Ranking 1

I have made no attempt to rank the protein crystallization program on NASA's Implementation Criteria since most of these depend on budget and schedule projections that are currently undetermined or are unknown to me.

Noel D. Jones, Ph.D.
June 4, 2002

July 23, 2002
DISSENT FROM THE ReMAP TASK FORCE REPORT

The ReMAP process and product are fundamentally flawed, so I must dissent from many of its conclusions. While there are many reasons for my dissent, some of the most fundamental ones are explained below.

The Task Force's primary task was to prioritize research, especially ISS research, to achieve maximum scientific impact. A part of the ReMAP Task Force's membership believes that meaningful scientific research cannot be done within the constraints of Core Complete construction and current shuttle schedules. However, it is my opinion that there is a considerable amount of excellent scientific work in the physical sciences and commercial programs that can be done within Core Complete and with the scheduled shuttle flights, thus fulfilling the mandate to identify good work in an era of fiscal constraints. Much of this work is consistent with the NASA goal of improving life on earth.

The "boxes," or research categories referred to in the ReMAP report were established early and remained unchanged despite vocal opposition by several members of the committee. This use of predefined "boxes" is contradictory to the charge of maximizing and prioritizing research for NASA. The research programs contained within these boxes were reviewed in only a very cursory manner and the relationships between programs were virtually ignored. These "boxes" artificially categorized the research programs and predetermined many of the ReMAP report's conclusions.

An underlying problem with the entire ReMAP process and product is that there was not sufficient time or resources given to the Task Force members to do a proper job of prioritizing the research programs for NASA. Additionally, these constraints limited the ability of the Task Force members to fully participate in reviewing the information, which has been published as ReMAP conclusions.

It is with a great deal of regret that I feel compelled to write this dissent, rather than issue a minority report. However, my concerns are fundamental to what I perceived as my responsibilities as a member of the ReMAP Committee and articulated early in the process, but was not completely reflected in the report.

Signed:

Raymond J. Bula

July 23, 2002
DISSENT FROM THE ReMAP TASK FORCE REPORT

The ReMAP process and product are fundamentally flawed, so we must dissent from its conclusions. While there are many reasons for our dissent, we have explained the most fundamental ones below.

The committee's primary task was to prioritize research, especially ISS research, to achieve maximum scientific impact. A part of the ReMAP committee's membership believes that meaningful scientific research cannot be done within the constraints of Core Complete construction and current shuttle schedules. However, it is our opinion that there is a considerable amount of excellent scientific work in the physical sciences and commercial programs that can be done within Core Complete and with the scheduled shuttle flights, thus fulfilling the mandate to identify good work in an era of fiscal constraints. Much of this work is consistent with the NASA goal of improving life on earth.

The “boxes,” or research categories referred to in the ReMAP report were established early and remained unchanged despite vocal opposition by several members of the committee. This use of predefined “boxes” is contradictory to the charge of maximizing and prioritizing research for NASA. The research programs contained within these boxes were reviewed in only a very cursory manner and the relationships between programs were virtually ignored. These “boxes” artificially categorized the research programs and predetermined many of the ReMAP report’s conclusions.

An underlying problem with the entire ReMAP process and product is that there was not sufficient time or resources given to the committee members to do a proper job of prioritizing the research programs for NASA. Additionally, these constraints limited the ability of the committee members to fully participate in reviewing the information, which has been published as ReMAP conclusions. For example, the entire committee was not given the opportunity to review the narrative sections of the Executive Summary prior to it being presented to the NAC. And finally, the complete final ReMAP report was not distributed to the entire committee in a timely manner for considered review.

It is with a great deal of regret that we feel compelled to write this dissent, rather than issue a minority report. However, our concerns are fundamental to what we perceived as our responsibilities as members of the ReMAP Committee and were articulated early in the process, but were not reflected in the final report.

Signed:

Andreas Acrivos Patricia Morris
Elaine Oran Pierre Wiltzius

July 24, 2002
DISSENT FROM THE ReMAP TASK FORCE REPORT

The ReMAP process and product are fundamentally flawed, so I must dissent from its conclusions. While there are many reasons for this dissent, I strongly support the most fundamental ones described below.

The committee's primary task was to prioritize ISS research to achieve maximum scientific impact. A part of the ReMAP committee's membership believes that meaningful scientific research cannot be done within the constraints of Core Complete construction and current shuttle schedules. (Such a statement was even reported in the media.) However, it is my considered opinion that there is a very much excellent scientific work in the physical sciences and commercial programs that can be done within Core Complete and with the scheduled shuttle flights, thus fulfilling the mandate to identify good work in an era of fiscal constraints. Much of this work is consistent with the NASA goal of improving life on earth.

The "boxes," or research categories referred to in the ReMAP report were established early and remained unchanged despite vocal opposition by several members of the committee. This use of predefined "boxes" is contradictory to the charge of maximizing and prioritizing research for ISS. The research programs contained within these boxes were reviewed in only a very cursory manner and the relationships between programs were virtually ignored. These "boxes" artificially categorized the research programs and predetermined many of the ReMAP report's conclusions.

An underlying problem with the entire ReMAP process and product is that there was not sufficient time or resources given to the committee members to do a proper job of prioritizing the research programs for ISS. Perhaps more important, these constraints limited the ability of this committee member to fully participate in reviewing the information, which has been published as ReMAP conclusions. For example, the entire committee was not given the opportunity to review the narrative sections of the Executive Summary prior to it being presented to the NAC. And finally, the complete final ReMAP report was not distributed to the entire committee in a timely manner for considered review.

Thus it is with a great deal of regret that I feel compelled to write this dissent, rather than issue a minority report. However, my concerns are fundamental to what I perceived as my responsibilities as a member of the ReMAP Committee. These and many others were articulated in the process, but were not reflected in the final report.

Regretfully,

Harold Metcalf
Professor of Physics and
Distinguished Teaching Professor

APPENDIX O: Nomenclature

AEMC	Advanced Environmental Monitoring and Control
AEVA	Advanced Extravehicular Activity
AHST	Advanced Human Support Technology
ALS	Advanced Life Support
BRC	Biomedical Research and Countermeasures
CO_2	Carbon Dioxide
CSA	Canadian Space Agency
CSC	Commercial Space Center
DARPA	Defense Advanced Research Projects Agency
ECLSS	Environmental Control and Life Support System
EMC	Environmental Monitoring and Control
EMCS	European Modular Cultivation System
ERTD	Engineering Research and Technology Development
ESA	European Space Agency
EVA	Extravehicular Activity
FSB	Fundamental Space Biology
FY	Fiscal Year
GNP	Gross National Product
GPS	Global Positioning System
HF	Human Factors
HZE	High Energy
IMCE	International Space Station Management and Cost Evaluation
IOM	Institute of Medicine
IP	International Partners
ISS	International Space Station
LEO	Low Earth Orbit
MSFC	Marshall Space Flight Center
NAC	NASA Advisory Council
NAPA	National Academy of Public Administration
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCI	National Cancer Institute
NIH	National Institute of Health
NRC	National Research Council
NSF	National Science Foundation
OBPR	Office of Biological and Physical Research, NASA
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
R&D	Research and Development
R&TD	Research and Technology Development
ReMAP	Research Maximization and Prioritization
SHFE	Space Human Factors Engineering
STS	Space Transportation System
TRL	Technology Readiness Level
XCF	X-ray Crystallography Facility

ISS Configurations

US Core Complete
The configuration of the ISS includes the US Lab (12 research racks) and assembly through Node 2. It does not include the European Laboratory Module, the Japanese Experiment Module, nor the Centrifuge Accommodations Module. This configuration is established in 2004. This configuration assumes that the available crew time for all research is 20 hours per week (based on a permanent crew of three).

US + IP Core Complete
The configuration of the ISS following assembly of the Centrifuge Accommodations Module (4 US racks); includes the European Laboratory Module (5 US racks) and the Japanese Experiment Module (5 US racks). This configuration is established in 2007/2008. This configuration assumes that the available crew time for all research is 20 hours per week (based on a permanent crew of three).

Enhanced
The configuration of the ISS following addition of crew support systems which will allow an increase in the crew size. This configuration assumes that the available crew time for all research is 160 hours per week (based on a permanent crew of six).